CENOZOIC SYNTECTONIC SEDIMENTATION AND STRIKE-SLIP BASIN DEVELOPMENT ALONG THE DENALI FAULT SYSTEM, YUKON TERRITORY

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ABSTRACT

This is a multidisciplinary study which combines sedimentology and sedimentary petrology, palynology, organic petrology and structural analysis of the middle Cenozoic Amphitheatre Formation in the St. Elias Mountains, and documents syntectonic deposition in strike-slip basins along the Denali fault system. The outcrops of the Amphitheatre Formation can be divided into two discrete basins: the northern Burwash basin and the southern Bates Lake basin.

Sedimentological analysis of the Burwash basin identified fault-controlled depocenters which allowed the development of several different types of non-marine depositional environments in close proximity. Palynology and organic petrology data indicate that the Amphitheatre Formation is diachronous and spans the Eocene-Oligocene boundary.

Light-mineral provenance studies of sandstones, clast-counts in conglomerates and paleocurrent analyses suggest that the Wrangellia and Yukon Crystalline Terranes were sources for the Amphitheatre Formation in the Burwash basin. In contrast, preliminary work suggests that Wrangellia and possibly the Gravina-Nutzotin Terrane may have been important sources for the Amphitheatre Formation in the Bates Lake basin.

Structural data combined with geologic mapping indicate a predominance of strike-slip deformation during and after deposition of the Amphitheatre Formation in the Burwash basin. The presence of syndepositional faults with subhorizontal slickensides indicates that strike-slip deformation occurred during deposition of the Amphitheatre sediments. The Burwash basin contains structures indicative of both contractional and strike-slip deformation, whereas the Bates Lake basin contains structures indicative of both extensional and strike-slip deformation. The change in structural style between the two basins suggests that the Amphitheatre Formation may have been deposited in transpressional as well as transtensional tectonic settings along individual segments of the Denali fault system during the middle Cenozoic.

RÉSUMÉ

Cette étude multidisciplinaire combine la sédimentologie, la pétrologie sédimentaire, la palynologie, la pétrologie organique et l'analyse structurale de la formation d'Amphitheatre du Cénozoïque moyen dans les monts St. Elias et on y documente le dépôt syntectonique dans les bassins de décrochement le long du système de Denali. Les affleurements de la formation d'Amphitheatre peuvent être répartis comme appartenant à deux bassins discrets : le bassin septentrional de Burwash et le bassin méridional du Lac Bates.

L'analyse sédimentologique du bassin de Burwash a permis d'identifier les dépocentres limités par des failles où ont pu se former en étroite proximité plusieurs types différents de milieux de sédimentation non marins. Les données palynologiques et de pétrologie oprganique indiquent que la formation d'Amphitheatre est diachrone et chevauche la limite Éocène-Oligocène.

Des études de la provenance des minéraux clairs des grès, des dénombrements des fragments dans les conglomérats et des analyses des paléocourants suggèrent que les terranes Wrangellia et Cristallin du Yukon constituaient les sources pour la formation d'Amphitheatre dans le bassin de Burwash. Par contraste, des travaux préliminaires suggèrent que la Wrangellia et le terrane de Gravina-Nutzotin ont pu constituer des sources importantes pour la formation d'Amphitheatre dans le bassin du Lac Bates.

Les données structurales combinées aux données de la cartographie géologique indiquent une prédominance de déformations de décrochement pendant et après le dépôt de la formation d'Amphitheatre dans le bassin de Burwash. La présence de failles contemporaines de la sédimentation avec surfaces de friction subhorizontales indique que la déformation par décrochement s'est produite pendant le dépôt des sédiments de la formation d'Amphitheatre. Le bassin de Burwash renferme des structures indicatives de déformations par contraction et par décrochement alors que le bassin du Lac Bates renferme des structures indicatives de déformations par extension et par décrochement. Le changement de style structural d'un bassin à l'autre suggère que la formation d'Amphitheatre peut avoir été mise en place dans des cadres tectoniques de transpression ainsi que de transtension le long de segments individuels du système de Denali au Cénozoïque moyen.

INTRODUCTION

Middle Cenozoic coarse-grained sedimentary rocks, collectively referred to as the Amphitheatre Formation, were deposited in several small basins along or near the Shakwak-Dalton and Duke River segments of the Denali fault system in the eastern St. Elias Mountains (Fig. 1). The Amphitheatre Formation forms a narrow, discontinuous belt approximately 350 km long, following the southwest side of the Shakwak-Dalton fault (Campbell and Dodds, 1982a, 1982b). Because of their age, textural and compositional immaturity and proximity to the fault, it is possible that sedimentary rocks of the Amphitheatre Formation record much of the Cenozoic tectonic history of the eastern St Elias Mountains and the Denali fault system. Our ongoing study, combined with observations by Eisbacher and Hopkins (1977), strongly suggests that Amphitheatre sedimentation was coeval with movement on the Denali fault system. In addition, later folding and faulting of the Amphitheatre Formation indicates post-Amphitheatre deformation along the strike-slip system. The Amphitheatre Formation consists of 350 - 1100 m of conglomerate, sandstone, shale and coal (Read and Monger, 1976) and is considered an overlap assemblage because it was deposited across several juxtaposed, accreted terranes which comprise the eastern St. Elias Mountains (Fig. 1). The Amphitheatre Formation thus contains the only sedimentary record of middle Cenozoic movement on the Denali fault system, as well as the post-accretionary history of the terranes in southwest Yukon.

SEDIMENTOLOGY

The outcrops of the Amphitheatre Formation that we have studied can be divided into two discrete areas with contrasting petrofacies, structures and sedimentological characteristics. Each area represents the remnant of a separate basin. We refer to the northern area as the Burwash basin and the southern area as the Bates Lake basin.

Sedimentological data indicate that the Amphitheatre Formation is characterized by (1) abrupt and localized facies changes both laterally and vertically; (2) markedly different lithostratigraphies within the Burwash basin, suggesting the existence of small (10's km), discrete, fault-controlled depocenters; (3) abrupt changes in local paleocurrent direction within fault-controlled depocenters; and (4) ample evidence of syndepositional tectonism, including intraformational unconformities, syndepositional faults, angular scree deposits and boulder conglomerates (Ridgway et al., 1989; Cole et al., 1989; Eisbacher and Hopkins, 1977). These characteristics are common in strike-slip tectonic settings, where multiple source areas are tectonically transported along the basin margins and sedimentation is synchronous with deformation of the basin.

Northern Area - Burwash Basin

The Burwash basin is approximately 35 km long (Fig. 2) and can be differentiated into three depocenters which are

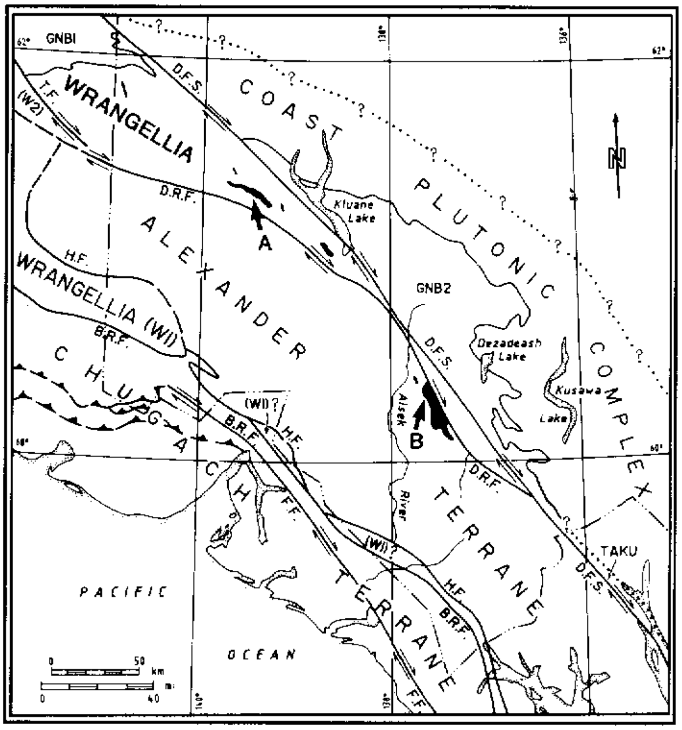

Figure 1: Regional geologic setting of the Amphitheatre Formation (black areas) in the Yukon Territory. The Amphitheatre Formation was deposited in several small basins along or near the Denali fault system in the eastern St. Elias Mountains. The Amphitheatre Formation, an overlap assemblage, overlies the Wrangellia Terrane in the northern part of the study area and the Alexander Terrane in the southern area. A - Burwash basin, B- Bates Lake basin, DRF - Duke River Fault, DFS - Denali Fault, GNB - Gravina-Nutzotin Belt, BRF - Border Range Fault, HF - Hubbard Fault, FF - Fairweather Fault. Modified from Campbell and Dodds, 1982a; 1982b.

defined by unique lithostratigraphies and distinctive depositional sequences. The unique stratigraphies representing individual depocenters cannot be correlated across major faults within the basin and are best exposed at the Mount Hoge, Amphitheatre Mountain and Cement Creek measured section localities (Fig. 2) (Ridgway et al., 1989).

Mount Hoge Depocenter

The Mount Hoge depocenter is the southernmost depocenter in the Burwash basin. It is located on the north flank of Mount Hoge at the southwest basin margin, and is characterized by proximal gravel-dominated fluvial deposits with poorly developed overbank facies. At Mt Hoge, the Amphitheatre Formation consists of sheet-like packages of clast-supported conglomerate 30-40 m thick, separated by 8 to 10-m thick units of interbedded sandstone and coal (Fig. 3-4). Conglomerate clast sizes range from pebble to cobble. Conglomerate lithofacies are established on the basis of trough and planar cross-stratification, crude horizontal stratification, and imbrication. Laterally extensive, sheet-form conglomerates showing sharp vertical separations between overbank and channelized facies suggest deposition on wet alluvial fans (Ethridge, 1985; Fraser and Suttner, 1986). Paleocurrent data indicate paleodrainage toward the west-northwest (Fig. 2).

Amphitheatre Mountain Depocenter

The next depocenter north of the Mount Hoge depocenter is the Amphitheatre Mountain depocenter (Fig. 2). It is characterized by proximal gravel-dominated fluvial deposits with well-developed overbank facies. At Amphitheatre Mountain, the basin fill consists of lenticular conglomerate packages 40 m thick, separated by well-developed sandstone, mudstone and coal packages ranging in thickness from 30 to 40 m (Fig. 5). In addition, the conglomerate packages grade laterally into finer-grained overbank facies (Fig. 6). The lack of extensive channel scouring, the well-developed channel-bar deposits (Fig. 7), and thick channel deposits that are laterally equivalent to coal deposits suggest deposition on a broad braidplain with well-established channel systems and perennial flow. This fluvial system may have been the central trunk stream into which more proximal, basin-margin streams discharged. Paleocurrent data indicate paleodrainage toward the west.

Cement Creek Depocenter

The Cement Creek depocenter is the northernmost depocenter in the Burwash basin (Fig. 2). Distal sandstone-dominated braided stream, lacustrine/fan-delta, and meandering stream deposits predominate. The stratigraphic sequence is characterized by three lower, 100 m thick, trough cross-bedded, conglomerate and coarse sandstone units which are overlain by 40m of mudstone and very fine-grained sandstone (probably lacustrine). These grade upward into laterally persistent (200 to 250 m wide) fine to medium-grained sandstone units of fan-delta affinity. This package is in turn overlain by a 50m thick unit of upward-fining, coarse to conglomeratic sandstone packages which were probably deposited by meandering streams (Fig. 8-9). Paleocurrent data indicate paleodrainage toward the south.

Southern Area - Bates Lake Basin

Initial work in the Bates Lake basin (Fig. 10) indicates that these sediments are characterized by abrupt changes in facies. However, confinement of depositional systems to specific fault-bounded depocenters, as is typical of the Burwash basin, has not been documented to date. Outcrops studied along the eastern basin margin (Fig. 11-12) (e.g. BL1 and BL2 on Fig. 10) consist of approximately 1,000 m of coarse, proximal alluvial-fan deposits which form an overall upward-fining sequence. Paleodrainage was toward the south-

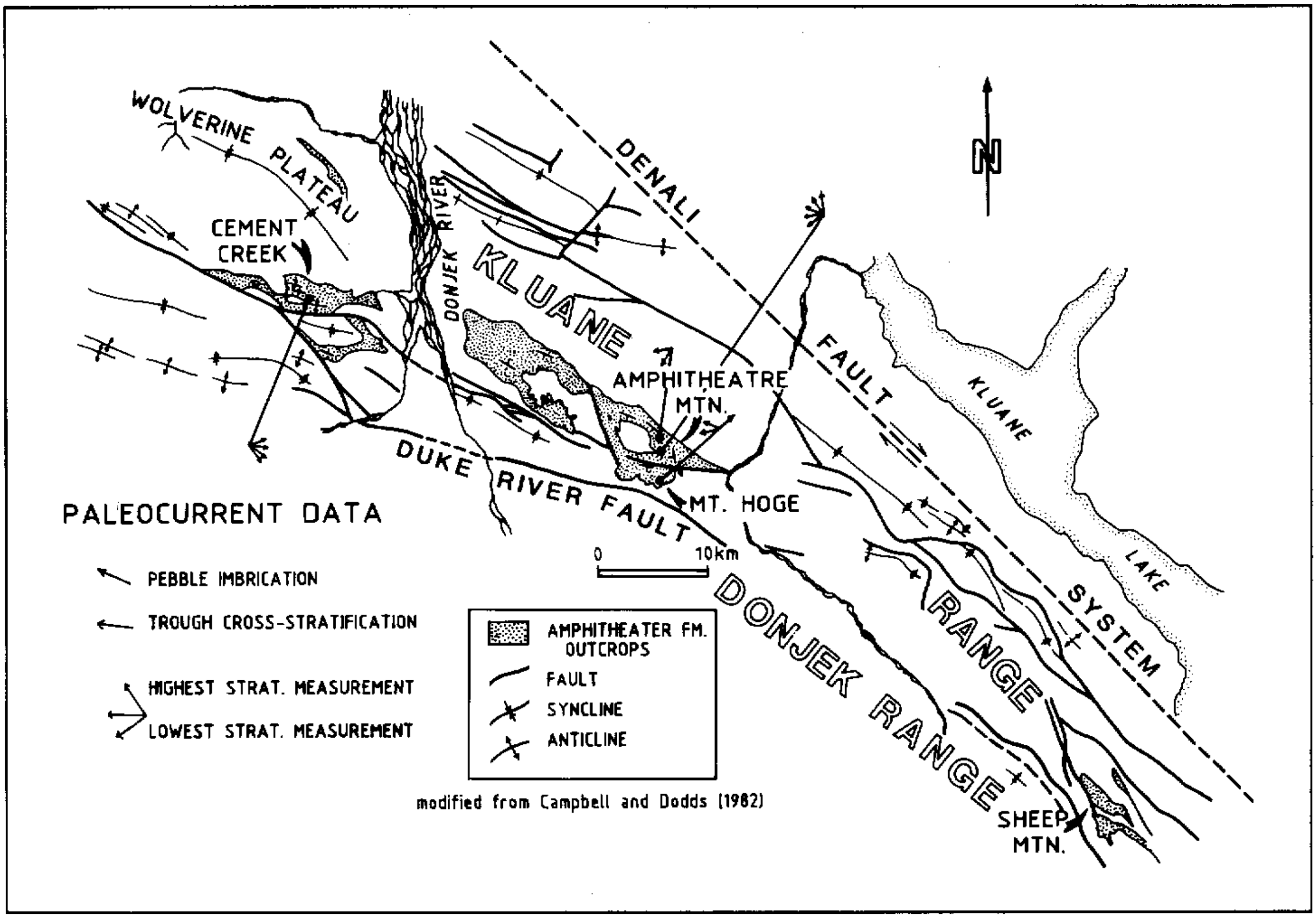

Figure 2: Location of stratigraphic sections measured in the Burwash basin. Map shows major folds and faults and outcrops of the Amphitheatre Formation based on Campbell and Dodds' (1982a; 1982b) maps. Leader lines connect clusters of paleocurrent arrows (from trough cross-strata and pebble imbrications) to their respective localities.

southwest. Outcrops along the southwest basin margin (Fig. 13)(e.g. WC2 on Fig. 10) consist predominantly of lenticular, coarse to medium-grained sandstones, encased in mudstones and siltstones which were probably deposited in a distal, axial fluvial system.

PALYNOLOGY AND ORGANIC PETROGRAPHY

Ongoing palynology and coal petrography studies document diachronous filling of the Burwash basin, spanning the Eocene-Oligocene boundary (Ridgway et al., 1989). The palynology and coal petrography support the model of localized fault-controlled depocenters within the Burwash basin. Owing to the structural complexities in ancient strike-slip basins, it becomes important to document the chronology and distribution of sediment packages in different parts of individual basins to understand the history of basin development. Our current interpretation of specific fault-bounded depocenters in the Burwash basin and the documentation of specific pollen and coal-type domains within these depocenters indicates the sediment packages become younger toward the basin center. This in turn suggests that the Burwash basin closely resembles the pull-apart model of strike-slip basin development (Crowell, 1974; Aydin and Nur, 1982; Mann et al., 1983). The pull-apart model constrains the oldest sediment to the perimeter of the basin, with sediments becoming progressively younger toward the center of the basin owing to structural enlargement of the basin with time. Studies of pollen types and coals in the Bates Lake basin are in progress.

Palynology

Palynological data indicate that the Amphitheatre Formation in the Burwash basin spans the Eocene-Oligocene boundary, which is marked by a global temperature decline. The global temperature decline resulted in a shift from angiosperm-dominated to gymnosperm-dominated forest types.

In the Burwash basin, the change in forest character is documented by an angiosperm-dominated temperate deciduous

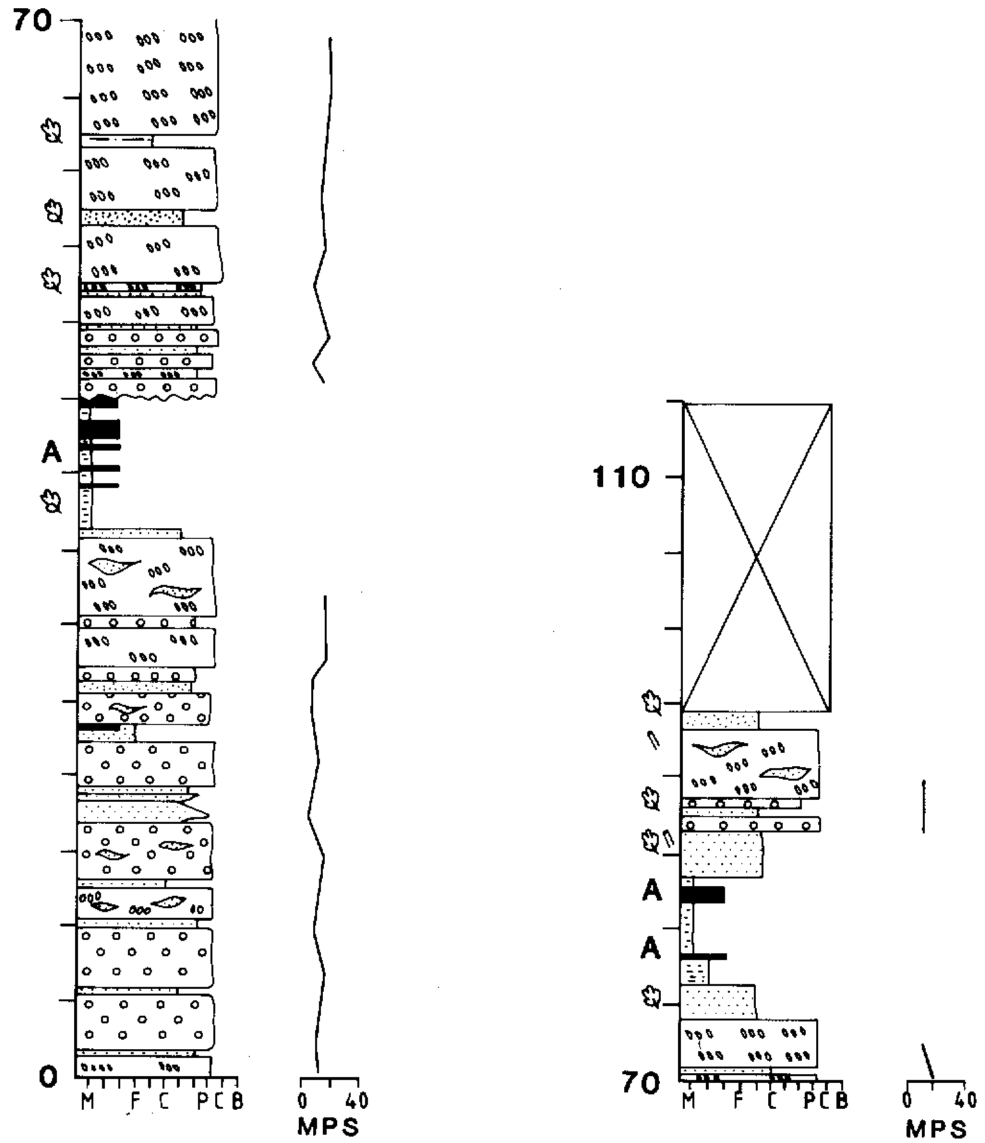

Figure 3: Measured stratigraphic section of the Amphitheatre Formation near Mount Hoge. Columns stack from left to right. Scale in meters on all measured sections. See Table 1 for explanation of lithofacies codes. Grain sizes: F - fine sand; M - medium sand; C - coarse sand; VC - very coarse sand; P - pebble; C - cobble; B - boulder. MPS = maximum particle size in cm.

pollen spectrum at the Mount Hoge and Cement Creek depocenters (Fig. 14) (see Fig. 2 for map locations), which contrasts with subtemperate, dominantly coniferous, forest pollen at the Amphitheatre Mountain depocenter (Fig. 14).

The difference in pollen dominances and the inferred forest character between depocenters suggest that Mount Hoge and Cement Creek localities on the perimeter of the basin are slightly older than the Amphitheatre Mountain locality in the more central part of the basin.

The oldest distinctive genus documented to date is Platycarya from the Cement Creek depocenter. In North America, Platycarya has mostly been found in Eocene rocks

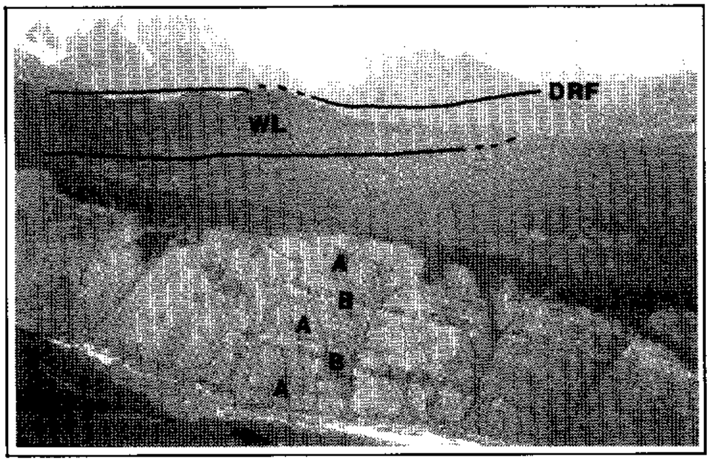

Figure 4: Typical exposures of the Mount Hoge depocenter consist of 30 to 40 m thick units of highly scoured, clast-supported conglomerate (A) that are separated by 8 to 10 m thick units of interbedded sandstone and coal (B). Two-man tent (arrow) for scale. DRF: Duke River Fault, WL: Wrangell Lavas.

(Tschudy and Scott, 1969, p.350), but Frederiksen and Christopher (1978) have recorded this genus in the upper Paleocene of South Carolina. The youngest distinctive genus is Carophyllaceae from the upper 10 meters of exposure at Amphitheatre Mountain. The oldest documentation of Carophyllaceae is from the middle Oligocene of New Zealand (Muller, 1981). Wiggins (1976) has also recognized Carophyllaceae in the well-dated middle Oligocene rocks of Cook Inlet, Alaska.

Organic Petrography

Petrographic studies of coal document the same change in the character of plant communities as recorded in the palynology studies, corresponding to the global temperature decline across the Eocene-Oligocene boundary. Petrographically, the coals of the three depocenters have low inertinite macerals (<6%) and most have high percentages of huminite macerals (>85%) (Fig.15). The huminite occurs in two distinctive populations correlated with the two different types of forest vegetation (Fig. 16). Coals at Mount Hoge (MINFILE 115G 011) and Cement Creek (MINFILE 115G 028) have more eu-ulminite B relative to eu-ulminite A, whereas the trend is reversed at the Amphitheatre Mountain depocenter (MINFILE 115G 012)(Fig. 16). Eu-ulminite A macerals are typical of subtemperate, conifer-dominated coal swamps (e.g. Amphitheatre Mountain), whereas eu-ulminite B and densinite are more typical of temperate, angiosperm-dominated coal swamps (e.g. Mount Hoge, Cement Creek). This change from temperate to subtemperate coal swamps with time probably resulted from the temperature decline across the Eocene-Oligocene boundary.

PROVENANCE

An ongoing objective of this study is to develop a better understanding of the relationship between the terranes comprising the eastern St. Elias Mountains, the Yukon Crystalline Terrane to the east, and the displacement history of individual segments of the Denali fault system which separate these terranes. The immature petrographic composition of the Amphitheatre Formation, combined with paleodrainage analysis, should be a very sensitive recorder of the relationship between the timing of fault movement and resultant sedimentation.

Several terranes are possible source areas for the Amphitheatre Formation (Fig. 1). The Wrangellia Terrane, which composes the Kluane Range, is a late Paleozoic terrane consisting of submarine volcanic-arc rocks, overlain by Triassic subaerial and submarine mafic volcanic rocks and shallow marine sedimentary rocks (Read and Monger, 1976; Campbell and Dodds, 1982a). The Alexander Terrane, which underlies the Icefield Ranges, is an early Paleozoic terrane consisting of carbonate, pelitic and volcanic rocks that are complexly deformed and metamorphosed to greenschist facies (Campbell and Dodds, 1982a). The Gravina-Nutzotin Terrane is an Upper Jurassic to Lower Cretaceous flysch basin composed of interbedded sandstone and shale (Eisbacher, 1976). The Yukon Crystalline Terrane, in the northern part of the study area, consists of high-grade metamorphosed Paleozoic rocks (Tempelman-Kluit, 1976; Mortensen and Jilson, 1985). All of these terranes are locally intruded by younger granitic rocks.

Sandstone Petrology

The detrital compositions of sandstones are directly related to the tectonic setting of the source area. Dickinson and Suczek (1979) used ternary diagrams to demonstrate the distinctiveness of detritus derived from different tectonic settings. In strike-slip settings, where source-area terranes of different rock types are juxtaposed along the basin margins, it may be informative to plot variables that characterize specific terranes. For example, the high-grade metamorphic rocks of the Yukon Crystalline Terrane would be the nearest "high-volume" source of polycrystalline quartz, whereas the volcanic rocks of the Wrangellia Terrane would be the nearest "high-volume" source of plagioclase and lithic volcanic and sedimentary rock fragments.

This "high-volume" sediment source characterization is not entirely satisfactory because of geological complexities at the local scale. For example, a local Cretaceous diorite intrusion within the volcanic-rich Wrangellia Terrane could easily have sourced part of the Amphitheatre Formation. To avoid misinterpretations due to local anomalous sources, we are collecting and analyzing sandstone samples on a basin-wide scale. A basin-wide data base should homogenize local source influences within the dominant source signature. Another complication is the possible former presence of supracrustal rocks above the metamorphic core of the Yukon Crystalline

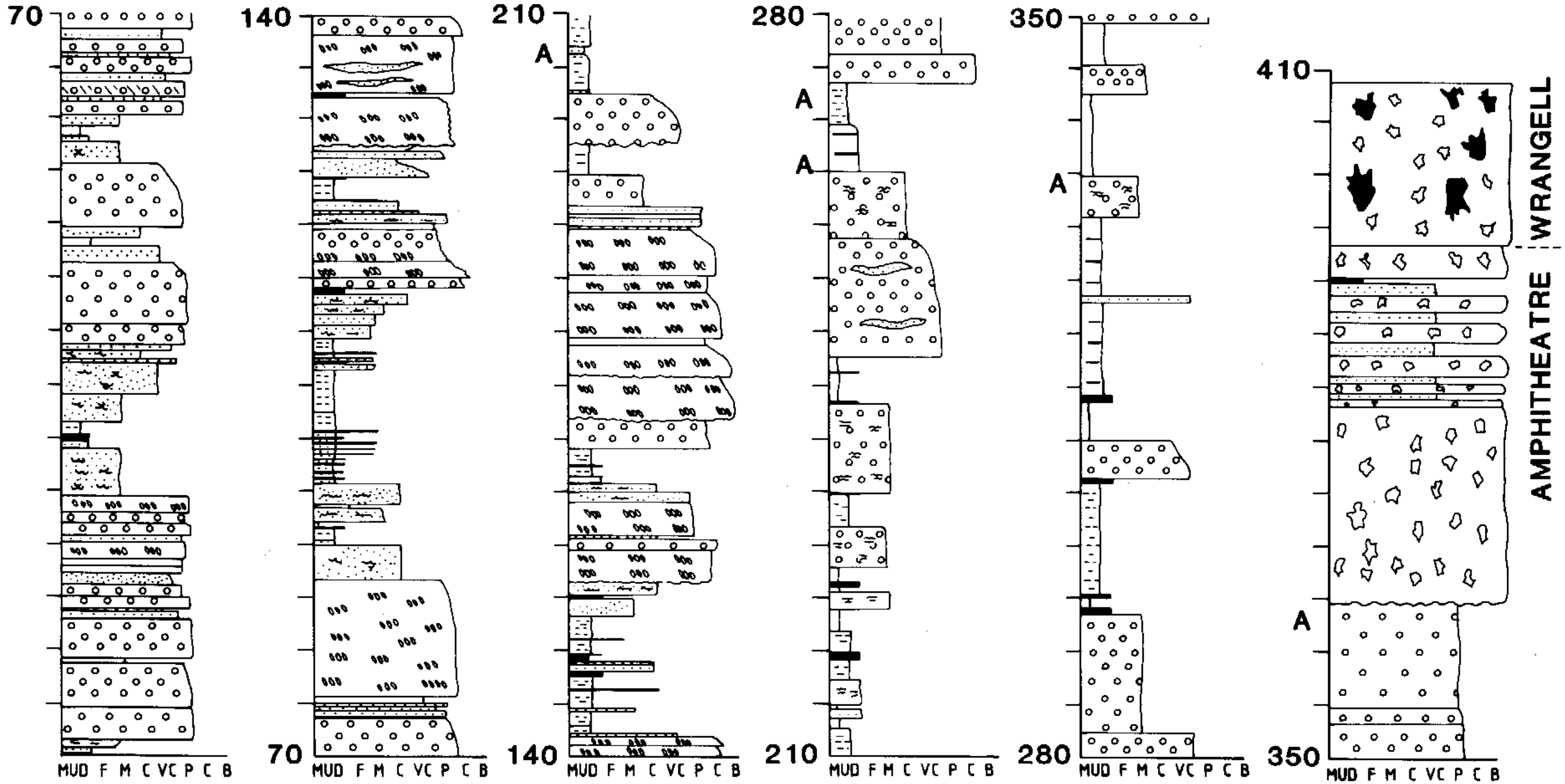

Figure 5: Measured stratigraphic section of the Amphitheatre Formation near Amphitheatre Mountain. Columns stack from left to right. See Table 1 and Figure 3 for explanation of lithofacies codes and grain sizes.

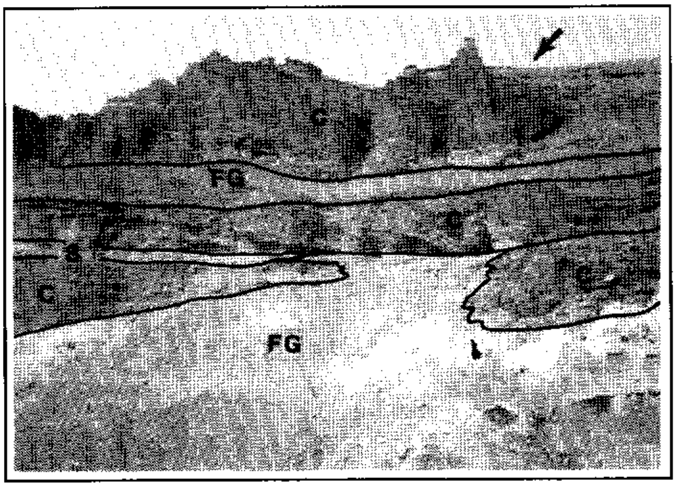

Figure 6: Individual amalgamated channels within channel complex interbedded with finer-grained facies at the Amphitheatre Mountain depocenter. Dall sheep (arrow) for scale. C - coarse, channel conglomerate; S - trough, cross-bedded sandstone; FG - finer-grained overbank deposits.

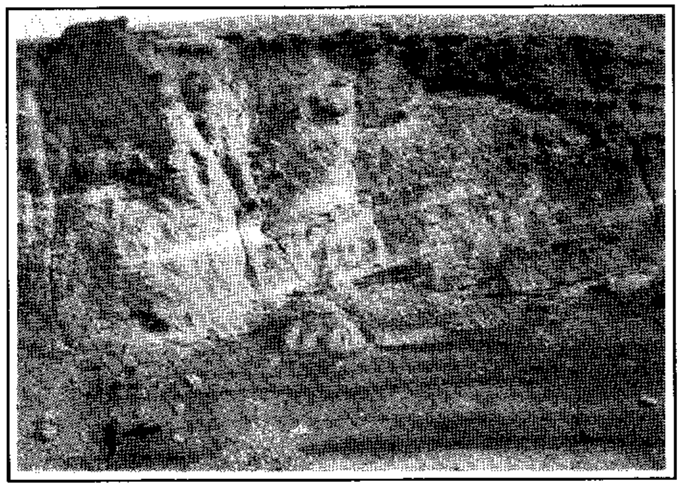

Figure 7: Well-developed foresets in channel-bar complex exposed at the Amphitheatre Mountain depocenter. Person (arrow) for scale.

Terrane and the Coast Plutonic Complex. These hypothetical supracrustal rocks are now completely eroded, but may have supplied sediment to the structural basins associated with the Denali fault system during the middle Cenozoic. If this is the case, any sediment contributed to the structural basins by the "supracrustals" should have contained a large component of metamorphic grains (e.g. Qp; Lm) by Eocene time based on studies (Tempelman-Kluit, 1976, p.1355; Mortensen and Jilson, 1985) which indicate that by the Late Triassic the entire eugeoclinal assemblage in the Yukon Crystalline Terrane (including the allochthonous Permian and older rocks) had undergone strong deformation and metamorphism. Therefore, any possible sediment contributed by the former supracrustal rocks would resemble the schists, gneisses, quartzites, and granitic rocks presently being eroded in the Yukon Crystalline Terrane and should not result in any gross misinterpretation.

Several trends are apparent in our preliminary sandstone petrology data. On QFL diagrams (Fig. 17a) sandstone compositions suggest mixing of continental block detritus (from sources rich in Q and F) and arc orogen detritus (from sources rich in F and L) in the Burwash basin. Together with paleocurrent data (Fig. 2) the petrologic data suggest that the most likely source for this particular sandstone composition is a mixture of sediments derived from Wrangellia and the Yukon Crystalline Terranes. Sandstones from the Bates Lake basin have QFL compositions that suggest a predominantly arc-orogen source (Fig. 17b). Combined with the south-southwestward paleocurrent data (Fig. 10), the Bates Lake petrologic data indicate derivation from Wrangellia and possibly the Gravina-Nutzotin Terrane.

On QpPK diagrams, sandstone compositions in both the Burwash and Bates Lake basins show marked enrichment in plagioclase (Fig. 18a,b) which, combined with paleocurrent data, suggests that the plagioclase-rich volcanic rocks of Wrangellia may have been the dominant source terrane during the filling of these basins.

Conglomerate Clast-Count Data

The identification of clast types in conglomerates within the Amphitheatre basins is an important tool for recognizing possible source areas. Because conglomerates are deposited in environments close to the source area, they accurately record source-area compositions. Clast-count data from the Amphitheatre conglomerates exposed in the Burwash basin indicate a predominance of local sources within the Wrangellia Terrane (Fig. 19). The conglomerates are dominated by meta-basalts (Fig. 20), meta-pelites and meta-tuffs (Fig. 21). We have field inspected and identified several potential source rocks in the Kluane Range (Wrangellia Terrane), including the Hasen Creek and Station Creek Formations (Pennsylvanian-Permian), the Nikolai volcanics (Triassic), and the Kluane Range intrusions (Cretaceous). Eisbacher and Hopkins (1977) suggested that the volcanic clasts in the Amphitheatre conglomerates were derived from Tertiary volcanic rocks (e.g. Mount Nansen - Eocene) which overlie parts of the metamorphic core of the Yukon Crystalline Terrane. At this stage in this study, we cannot rule out Eisbacher and Hopkins' interpretation. However, the coarseness of the conglomerates, abundant evidence for syndepositional faulting and syntectonic unconformities (see Structural Geology section), and the close proximity of the Wrangellia Terrane, finger the Wrangellia Terrane as a more likely source for the high volume of volcanic clasts in the Amphitheatre conglomerates. Future geochemical analysis of the volcanic clasts in the conglomerates may help to pinpoint their source rocks.

The relative abundance of high-grade metamorphic clasts in conglomerate in the Cement Creek depocenter parallels the greater abundance of polycrystalline quartz in the sandstones from Cement Creek. Both trends indicate that a minor

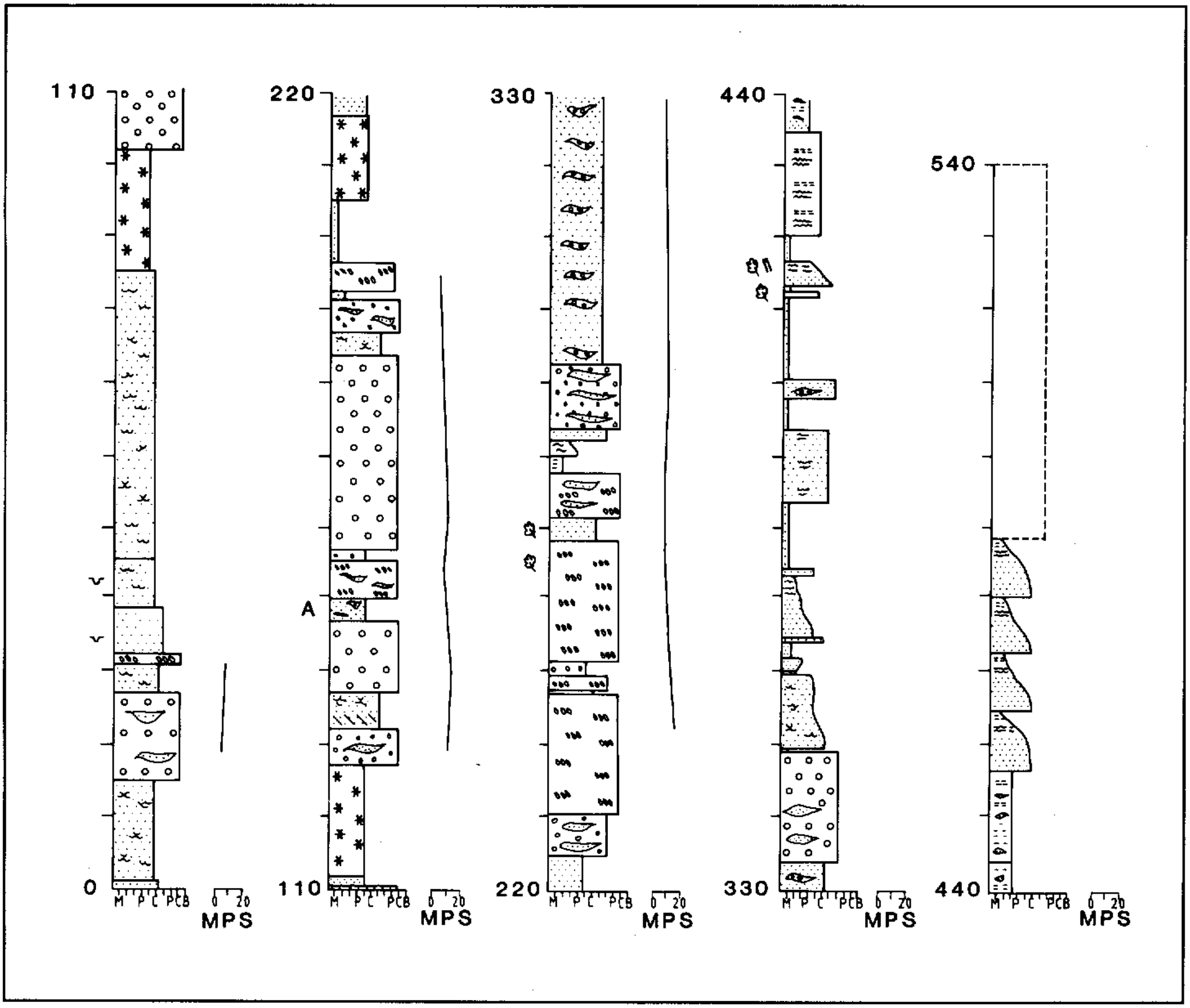

Figure 8: Measured stratigraphic section of the Amphitheatre Formation near Cement Creek. Columns stack from left to right. See Table 1 and Figure 3 for explanation of lithofacies codes and grain sizes.

component of the sediments deposited in the Cement Creek area was sourced from the high-grade metamorphic rocks of the Yukon Crystalline Terrane.

STRUCTURAL GEOLOGY AND BASIN DEVELOPMENT

A salient problem addressed by this study concerns the displacement histories of the Shakwak-Dalton and Duke River faults during and after Amphitheatre deposition. Most regional studies of the Denali fault system in the Yukon Territory and adjacent Alaska (Forbes et al., 1973a, 1973b, 1974; Eisbacher, 1976; Lanphere, 1978; Clague, 1979; Stout and Chase, 1980; Nokleberg et al., 1985; Plafker et al., 1989) indicate 300 - 400 km of displacement within a vaguely constrained time interval from Late Cretaceous to Recent.

Regional mapping in the study area by Campbell and Dodds (1978, 1982) and Read and Monger (1976) suggests that the major displacement was probably younger than early Late Cretaceous but older than Miocene. It appears certain that the Amphitheatre Formation was deposited during, and later deformed by, movements along these major strike-slip faults. Moreover, steeply-dipping slivers of Amphitheatre Formation rocks occur along the Shakwak-Dalton fault zone, indicating that further movement occurred during or after Amphitheatre deposition (Read and Monger, 1976).

In order to sort out the complicated relationships between the various fault systems and the Amphitheatre Formation, we are mapping the Amphitheatre Formation at a scale of 1:20,000. Detailed mapping of the Amphitheatre Formation

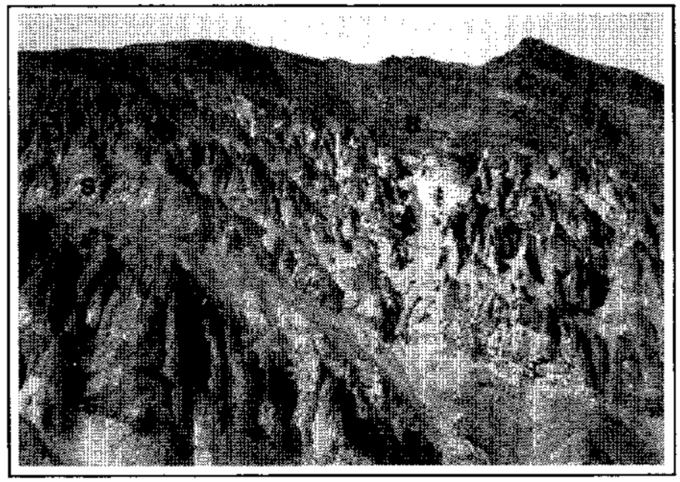

Figure 9: The stratigraphic succession at Cement Creek is characterized by three lower, 100 m thick conglomerate and coarse sandstone units (A), overlain by a 40 m-thick mudstone unit (B) which grades upward into laterally persistent fine to medium-grained sandstones (C). Exposure in photo is approximately 300 meters thick. Numerous sills (S) have intruded the lower part of the section.

is addressing the following questions: (1) What is the trend of deformation within the Amphitheatre in different parts of the basin(s) and how does it relate to the major regional strike-slip faults? (2) Are the present faulted Amphitheatre basin margins artefacts of post-Amphitheatre deformation or did these faulted margins actively control Amphitheatre sedimentation? This facet of the study is improving current understanding of fault movements between Late Cretaceous and Pliocene time, and indicates controls on basin development along the Denali fault system. Results to date indicate that obvious structural differences exist between the Burwash and Bates Lake basins.

Burwash Basin

The Burwash basin is characterized by: (1) fault-bounded margins which strike at oblique angles to the major strike-slip faults in the area; (2) right-stepping en echelon folds (Cement Creek area); (3) steeply dipping strata in local areas; and (4) intraformational unconformities (Sheep Creek area) and syndepositional faults (Amphitheatre Mountain area). These characteristics commonly are associated with basins developed in transpressional strike-slip settings (Lowell, 1972; Wilcox et al., 1973; Christie-Blick and Biddle, 1985).

Figure 22 is a geologic sketch map, completed during the summer of 1989, of the Amphitheatre Formation along the southern margin of the Burwash basin. This part of the basin displays contractional deformation. The southwest basin margin is an eastward trending asymmetric anticline, exposed along transect A-A'. The south limb is very gentle, whereas the north limb dips steeply and is truncated by a fault.

Several different structural styles are present in the small part of the basin mapped in Figure 22. A three-fold hierarchy of faults is present in this part of the Burwash basin; regional first-order faults, intra-basinal second-order faults, and syndepositional third-order faults. For example, at location B the "basement" rocks for this particular basin (e.g. Pv) have been juxtaposed against the Amphitheatre Formation along a set of conjugate high-angle NW-SE striking second-order faults (Fig. 23). In contrast, the structural style at location C is dominated by high-angle, NE-SW third-order syndepositional faults (Fig. 24). Slickenside orientation data (Figs. 25-26) indicate that at least the latest movements on the faults at both locations B and C have been primarily horizontal. Additional evidence that the basins were proximal to areas of active deformation includes boulder conglomerate deposits at Amphitheatre Mountain (Fig. 27) and Sheep Creek.

Comparison between the dominant NNW dip of bedding south of the major fault which parallels Granite Creek (a first-order fault, taken from Campbell and Dodds, 1982a) and the dominant SW dip of bedding north of the major fault suggests that fault-bounded segments of the basin may have acted as independent blocks and undergone different deformational histories. These contrasting structural histories should be identifiable as unique structural domains by field mapping.

Bates Lake Basin

In contrast to the Burwash basin, the Bates Lake basin is characterized by: (1) predominantly flat-lying strata; (2) little evidence of folding; (3) depositional onlap of the basin margins; and (4) numerous NE-SW striking faults which do not appear to rotate bedding. Initial work in the Bates Lake basin suggests that this basin has many of the characteristics of transtensional strike-slip basins, such as extensional structures (mainly normal faults) and a lack of en echelon folds (Wilcox et al., 1973; Harding et al., 1985; Christie-Blick and Biddle, 1985).

Figure 28 is a geologic sketch map of the southwest margin of the Bates Lake basin, located at the south end of Bates Lake (Fig. 10). The map demonstrates the extensional nature of this part of the basin. Note that the Amphitheatre Formation is exposed in two small graben within older "basement" rocks (e.g. locations A and B). The individual graben appear to have been rotated differentially, the rocks in the northernmost graben having a northeast dip and the rocks in the southwest graben having west-southwest dips. Clearly, this structural configuration of the Bates Lake basin is much different from that of the Burwash basin.

SUMMARY

Several lines of evidence indicate that deposition of middle Cenozoic coarse-grained sediments in small basins along or near the Shakwak-Dalton and Duke River segments of the Denali fault system was coeval with movement on the Denali fault system. This ongoing multi-disciplinary study of the Amphitheatre Formation is the first comprehensive study of

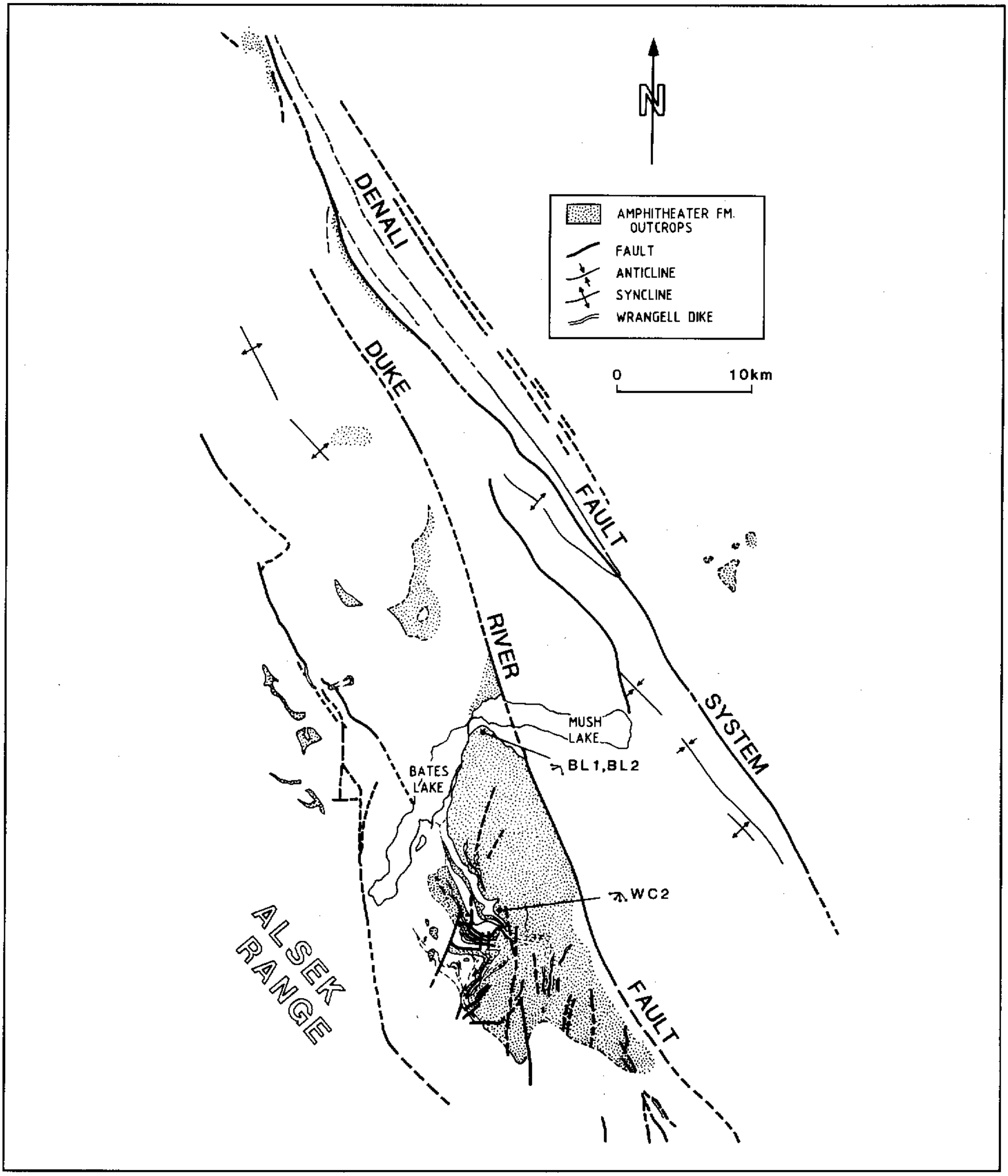

Figure 10: Location of stratigraphic sections studied in the Bates Lake basin. Map shows major folds and faults and outcrops of Amphitheatre Formation based on Campbell and Dodds' (1982a; 1982b) maps. Leader lines connect clusters of paleocurrent arrows (from trough cross-stratification and pebble imbrication) to their respective localities.

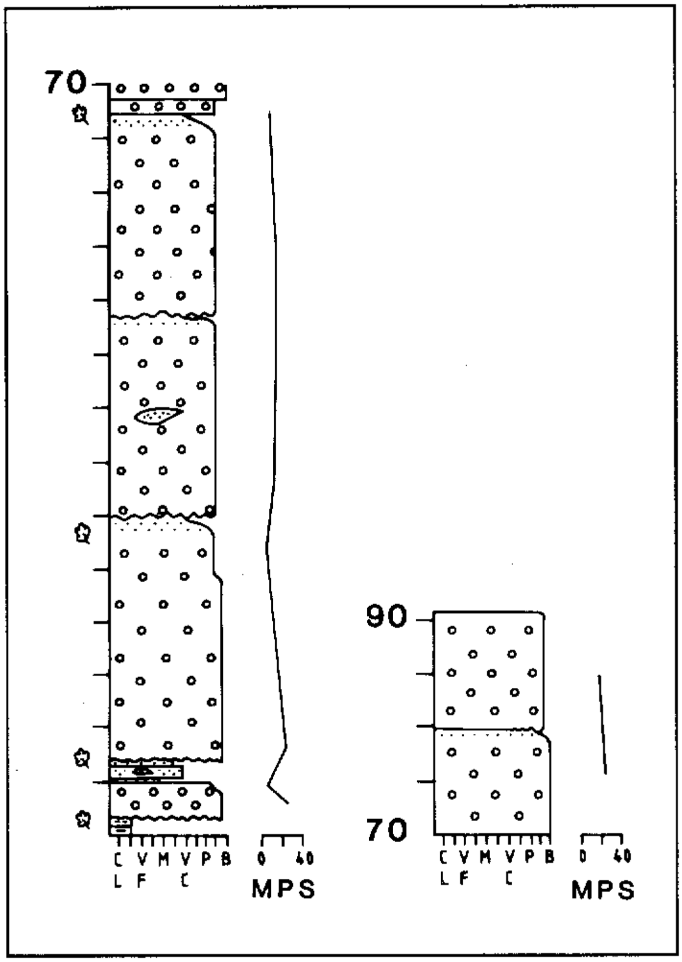

Figure 11: Measured stratigraphic section of the lower Amphitheatre Formation near the eastern margin of the Bates Lake basin. The section is dominated by 20 to 25 m thick units of pebble to boulder conglomerate. Columns stack from left to right. See Table 1 and Figure 3 for explanation of lithofacies codes and grain sizes.

these basins and sheds new light on the middle Cenozoic history of the eastern St Elias Mountains and the Denali fault system.

Sedimentological analysis of the Amphitheatre basins documents characteristics common to nonmarine strike-slip basins such as: (1) fault-controlled depocenters; (2) abrupt and localized facies changes; and (3) abrupt changes in local paleocurrent directions within each depocenter. The fault-controlled depocenters allowed several different types of depositional environments to exist in close proximity to each other within individual basins. Braided stream, wet alluvial fan, fan-delta, lacustrine and meandering stream deposits all occur within the Burwash basin, which is only 35 km in length and 5 km wide (Ridgway et al., 1989; Cole et al., 1989). The recognition and further documentation of wet alluvial-fan deposits may help clarify the depositional enigmas pointed out by Eisbacher (1978), Eisbacher and Hopkins (1977), and Long (1981) in Cenozoic rocks within the Canadian Cordillera intermontane basins. The intimate association of coarse clastics and coals, the lack of proximal alluvial-fan facies, and the non-conformity of the fluvial conglomerates to documented modern braided-stream deposits may be explained by a wet alluvial-fan depositional model.

Palynology and coal petrography document diachronous filling of the Burwash basin, which spanned the Eocene-Oligocene boundary. The global temperature decline at the Eocene-Oligocene boundary resulted in a change in forest character from temperate, angiosperm-dominated to subtemperate, gymnosperm (mainly coniferous)-dominated. Distinctive pollen and coal type domains within individual fault-bounded depocenters support the current interpretation of a pull-apart basin model for the Burwash basin.

Light-mineral provenance studies of sandstones and clast-types in conglomerates, combined with paleocurrent analyses, are helping to identify the possible source terranes for the Amphitheatre sediments. Our data suggest mixed continental block and arc-orogen sources of sand and gravel for the Burwash basin. The most likely candidates are the Wrangellia Terrane (for the volcanic lithic grains) and the Yukon Crystalline Terrane (for the high-grade metamorphic lithic grains). Meta-basalt, meta-pelite and meta-tuff are the most common conglomerate clast types in the Burwash basin and, combined with paleocurrent analyses, suggest local sources within the Wrangellia Terrane. The presence of local uplifted sources along the fault-bounded Amphitheatre basin margins, and evidence for syndepositional tectonism, supports a strike-slip origin for these basins.

Structural data indicate a predominance of strike-slip deformation during and after deposition of the Amphitheatre Formation in the Burwash basin. We have mapped high-angle faults of several orders including syndepositional faults which indicate strike-slip deformation during deposition of the Amphitheatre sediments. Second-order faults form a conjugate set of high-angle faults with subhorizontal slickensides indicating a predominance of oblique strike-slip fault movement.

The Burwash basin contains structures indicative of both contractional and strike-slip deformation, which is characteristic of basins developed in transpressional strike-slip settings.

Initial structural mapping in the Bates Lake basin indicates a graben and horst structural configuration along the basin margin, suggesting a major component of extensional deformation. The Amphitheatre Formation is exposed in small, fault-bounded graben bordered by older basement rocks along the Bates Lake basin margin. The Bates Lake basin has structures indicative of both extensional and strike-slip deformation, which is characteristic of basins developed in transtensional strike-slip settings.

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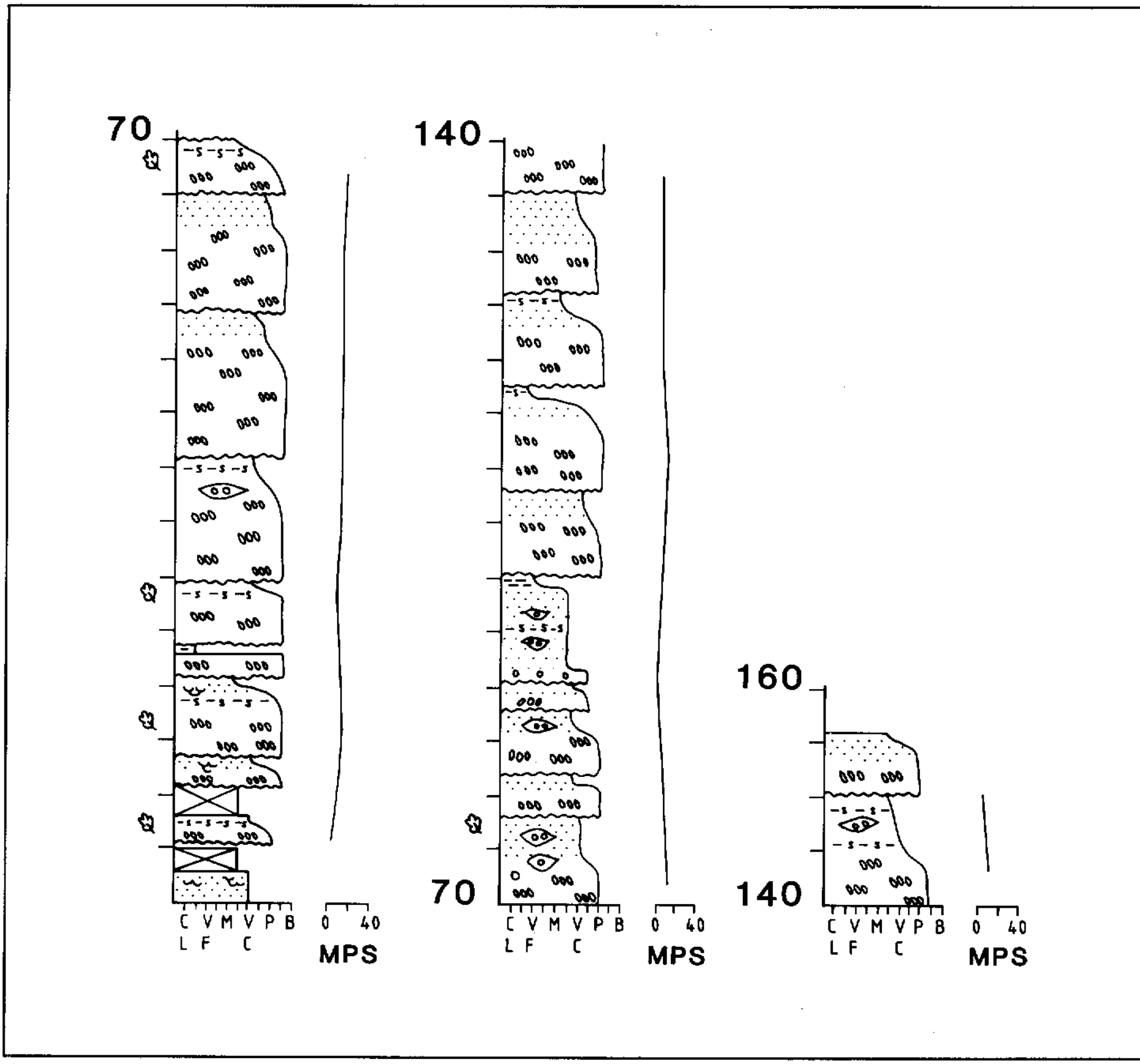

Figure 12: Measured stratigraphic section of the upper Amphitheatre Formation near the eastern margin of the Bates Lake basin. The section is dominated by 10 m thick units of pebble conglomerate which fine-upward. Columns stack from left to right. See Table 1 and Figure 3 for explanation of lithofacies codes and grain sizes.

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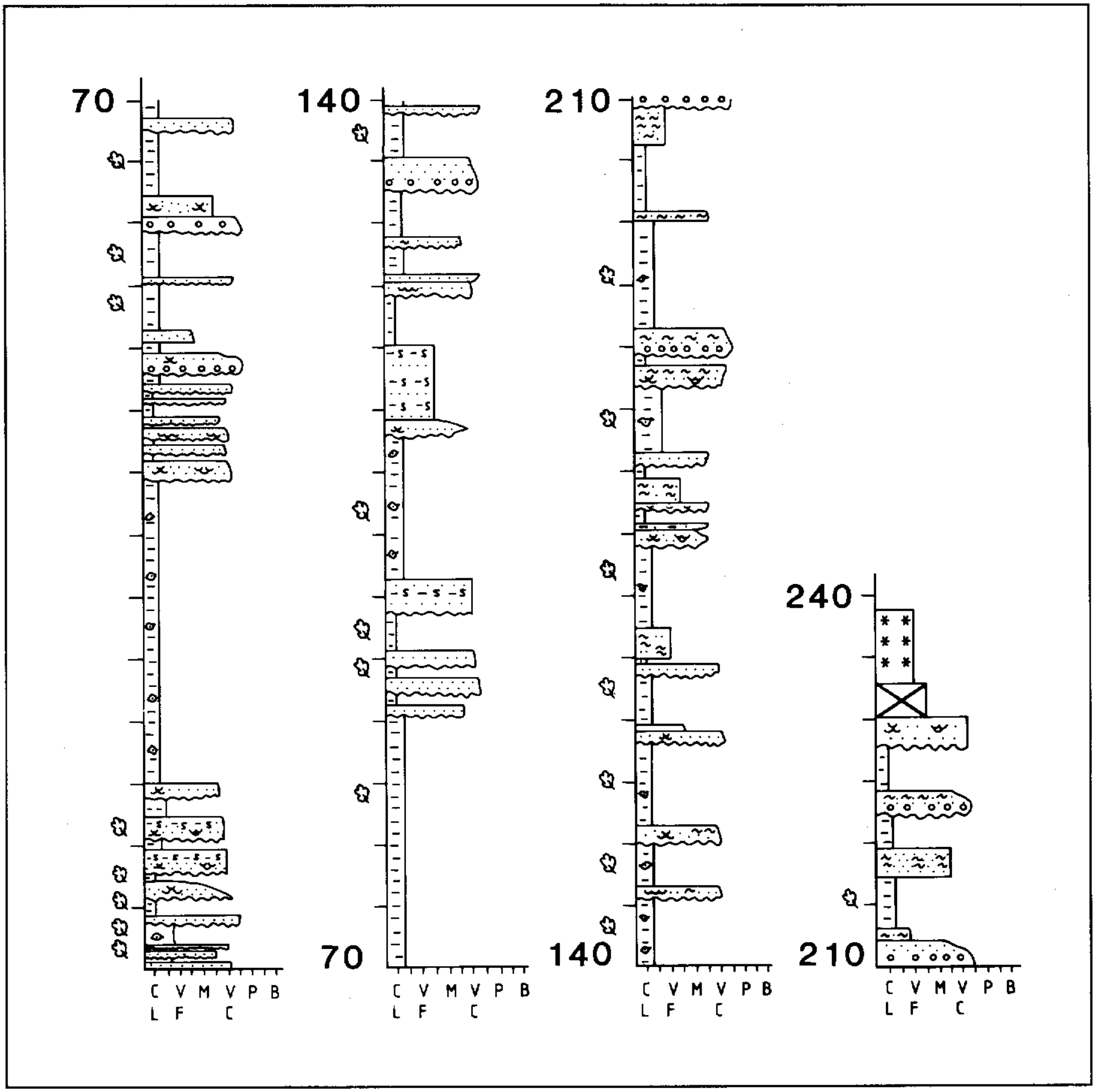

Figure 13: Measured stratigraphic section of the Amphitheatre Formation near the southwestern margin of the Bates Lake basin near Wolverine Creek. Columns stack from left to right. The section is dominated by sandstone lenses 2 to 3 m thick, which fine upward and are encased in mudstones. See Table 1 and Figure 3 for explanation of lithofacies codes and grain sizes.

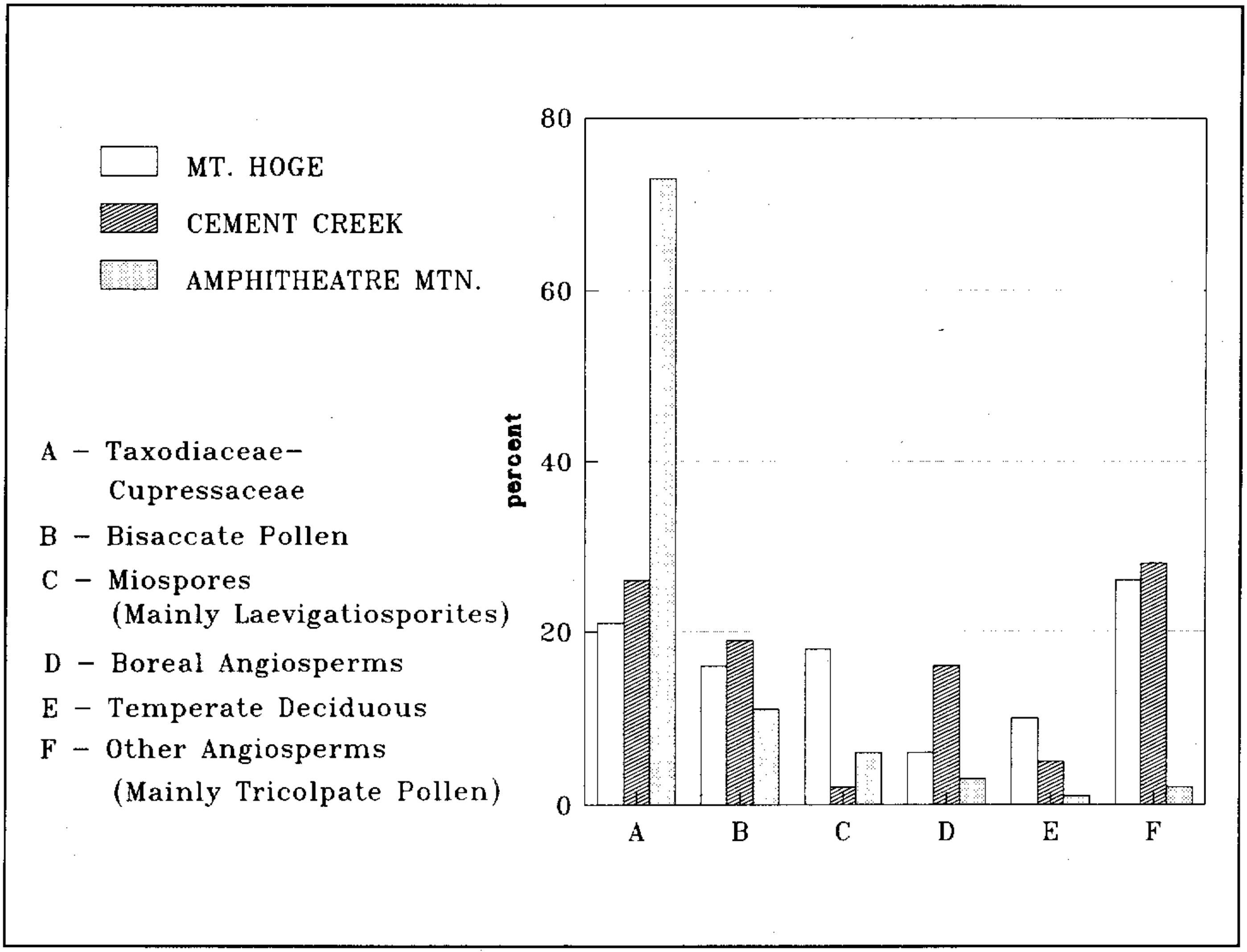

Figure 14: Histogram of the entire pollen spectrum documented for the Burwash basin. Percentages of coniferous pollen types are represented in columns A and B. Percentages of angiosperm pollen types are represented in columns D, E and F. Note the dramatic increase in coniferous pollen types at the Amphitheatre Mountain section relative to the Mount Hoge and the Cement Creek sections. Plots represent analysis of 23 fine-grained samples.

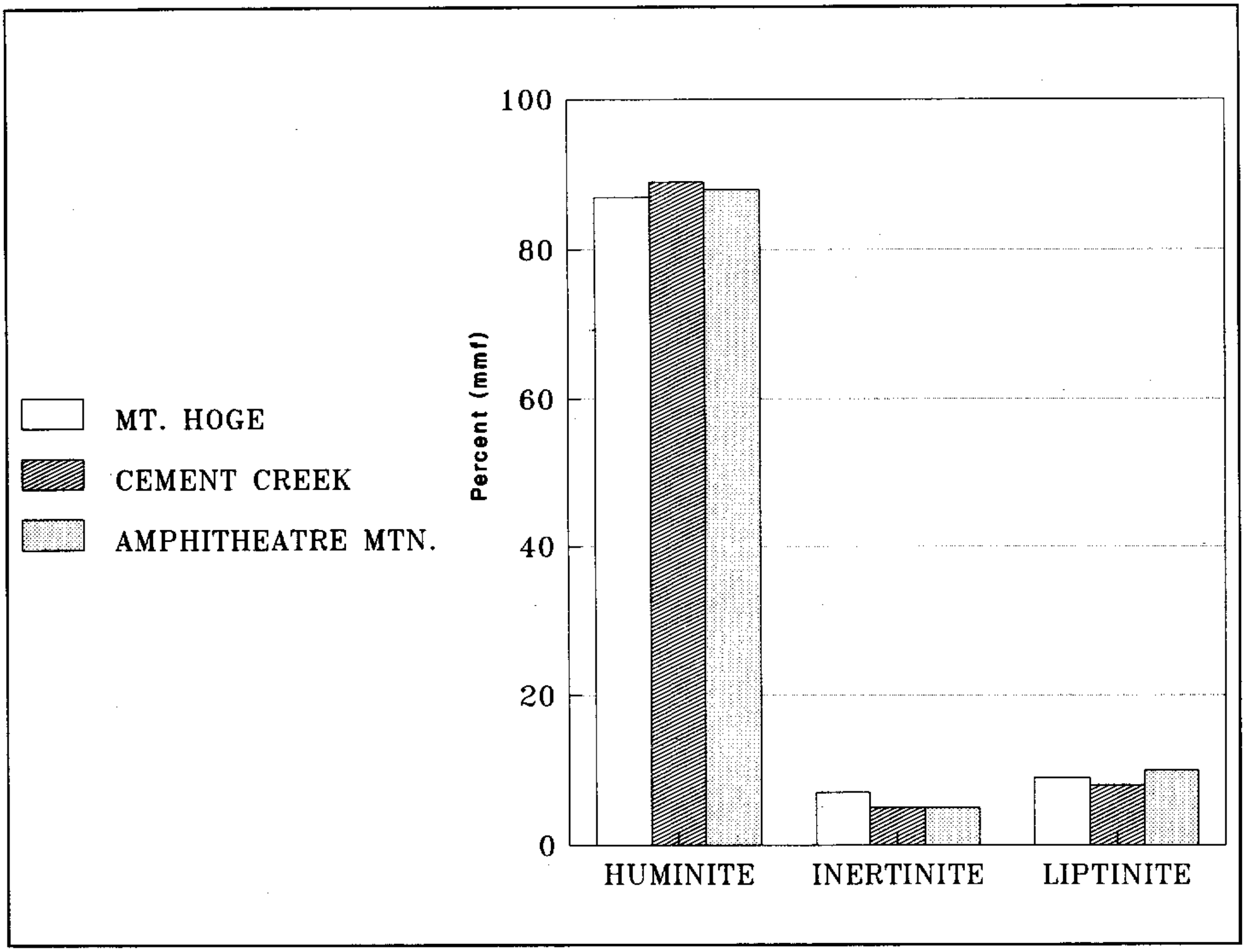

Figure 15: Histogram of maceral types in coal (lignite) from the Burwash basin.

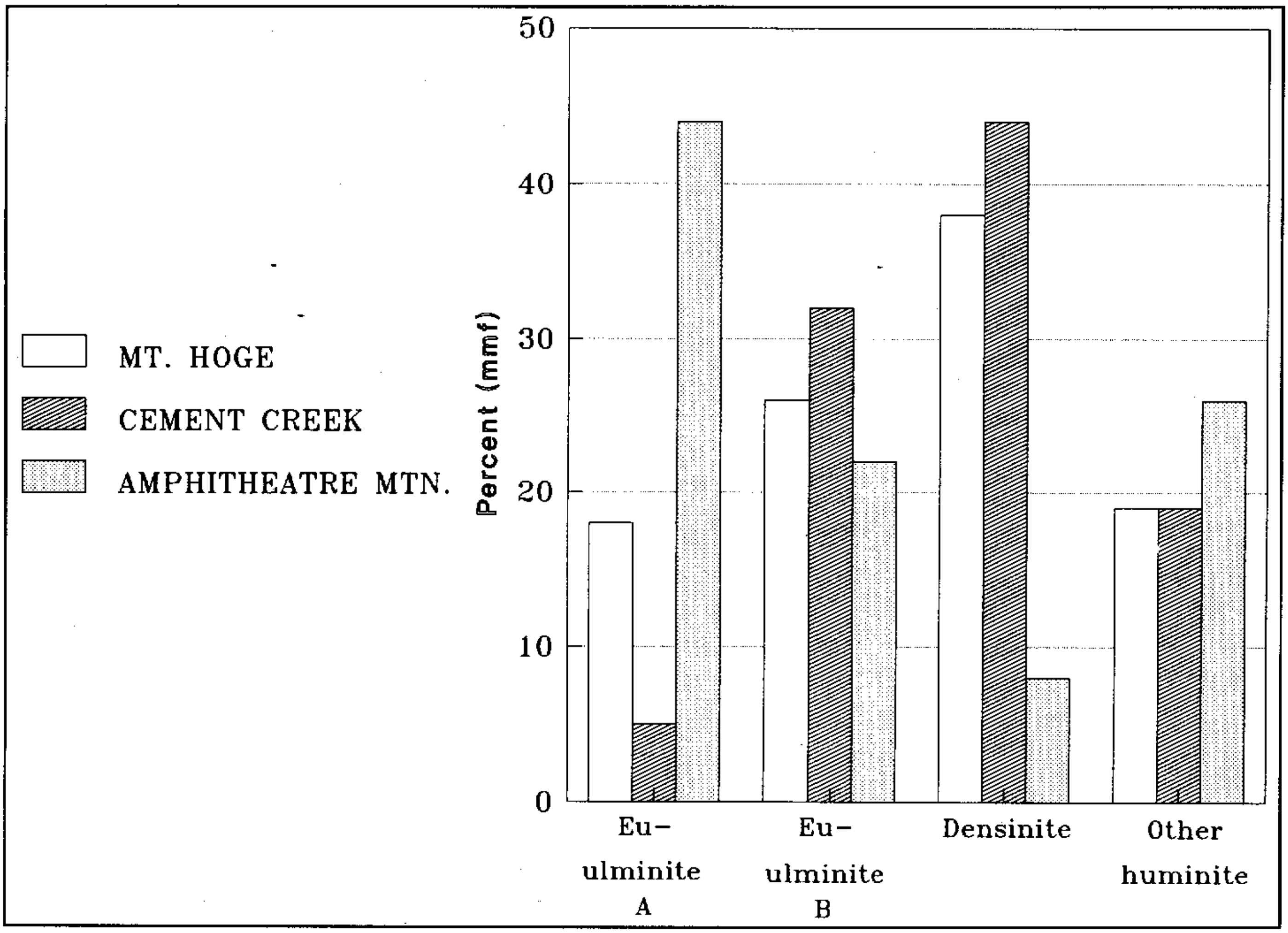

Figure 16: Histograms of individual components of the huminite maceral group for each section in the Burwash basin. Eu-ulminite A is believed to be the decomposition product of conifer wood whose cell walls are commonly impregnated with resin, wax and/or tannins. Eu-ulminite B is the decomposition product of non-coniferous angiosperm wood whose cell walls lack abundant impregnating substances. Densinite is the decomposition product of plants low in lignin and rich in cellulose, a characteristic of the angiosperm woods. Note the enrichment of eu-ulminite A, suggesting conifer-rich coal swamps at the Amphitheatre Mountain section, relative to eu-ulminite B and densinite rich coals located at the Mount Hoge and Cement Creek measured sections, correlating with angiosperm-rich palynomorph assemblages.

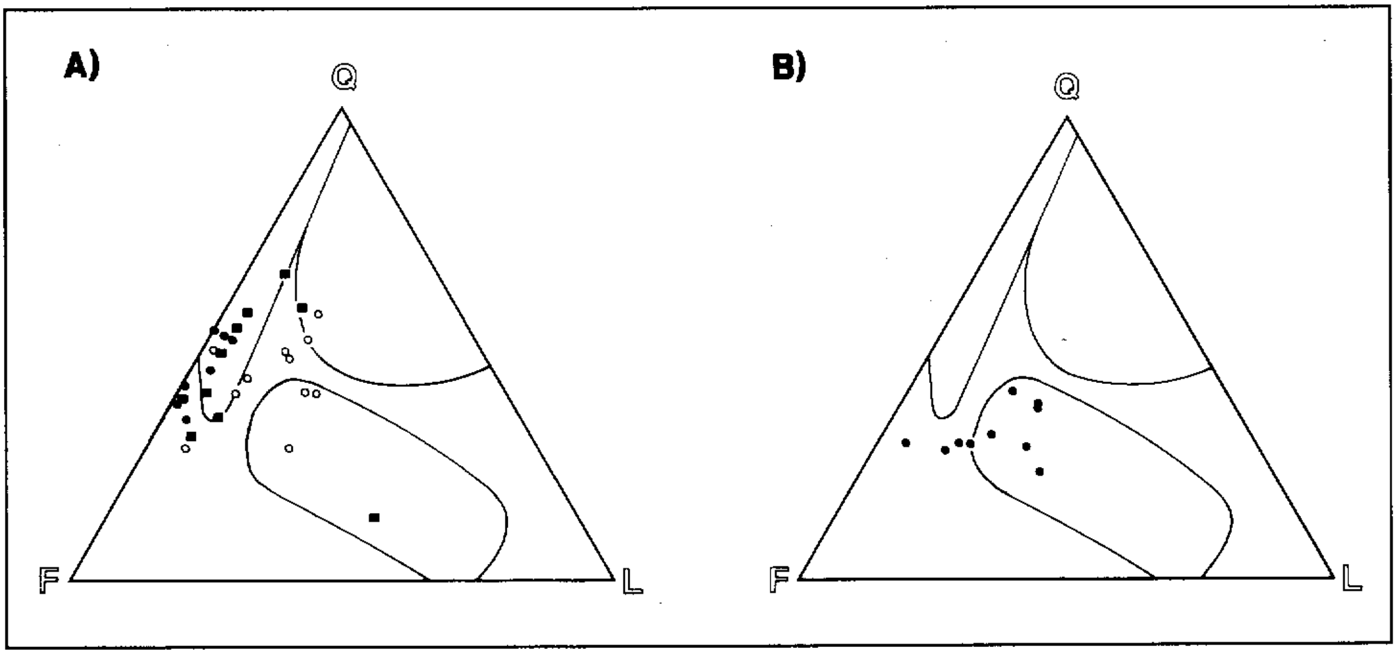

Figure 17: Ternary diagrams showing petrographic modal compositions of sandstones from the Amphitheatre Formation. A) Burwash basin; ● = Mount Hoge, ○ = Amphitheatre Mountain, ■ = Cement Creek; B) Bates Lake basin; Q = total quartz (including chert); F = total feldspar (including plagioclase and K-spar); L = unstable lithic fragments. See Figure 2 and Figure 10 for specific locations. Each point represents a modal analysis based on 450 counts per slide.

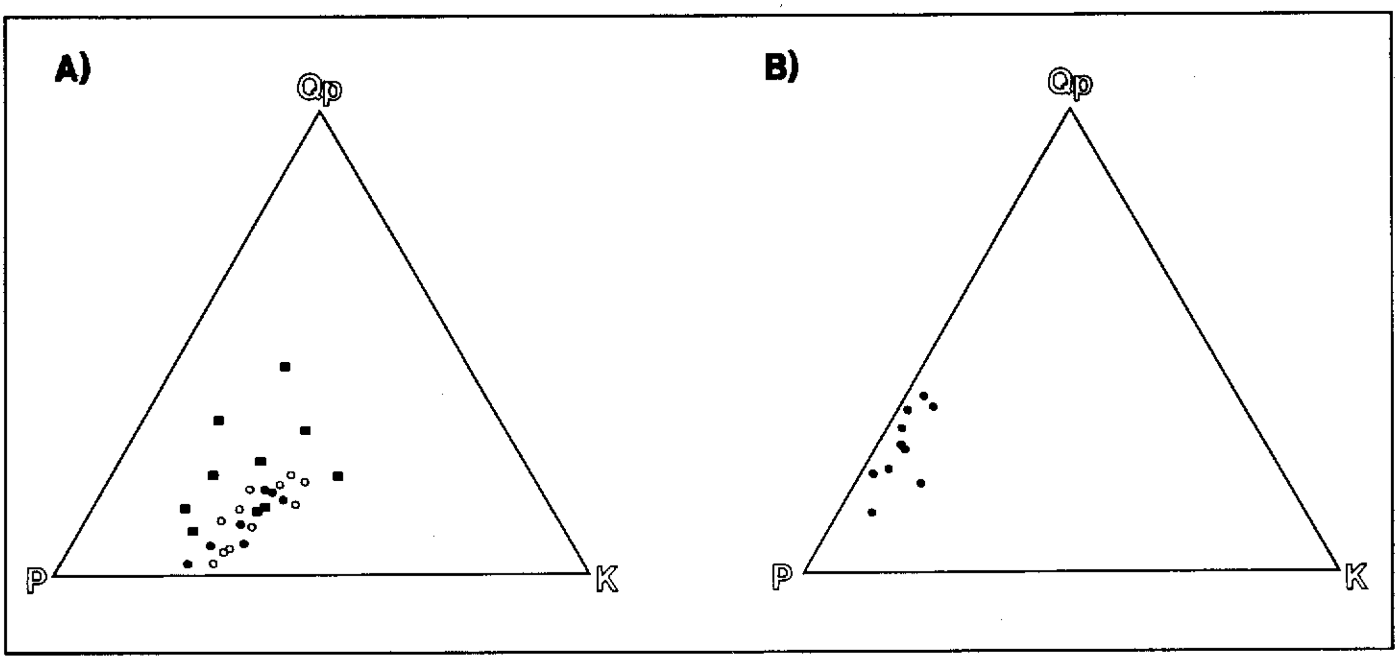

Figure 18: Ternary diagrams showing petrographic modal compositions of sandstones from the Amphitheatre Formation. A) Burwash basin; ○ = Amphitheatre Mountain, ■ = Cement Creek, ● = Mount Hoge; B) Bates Lake basin; Qp = polycrystalline quartz; P = plagioclase; K = potassium feldspar. See Figure 2 and Figure 10 for specific locations. Each point represents a modal analysis based on 450 counts per slide.

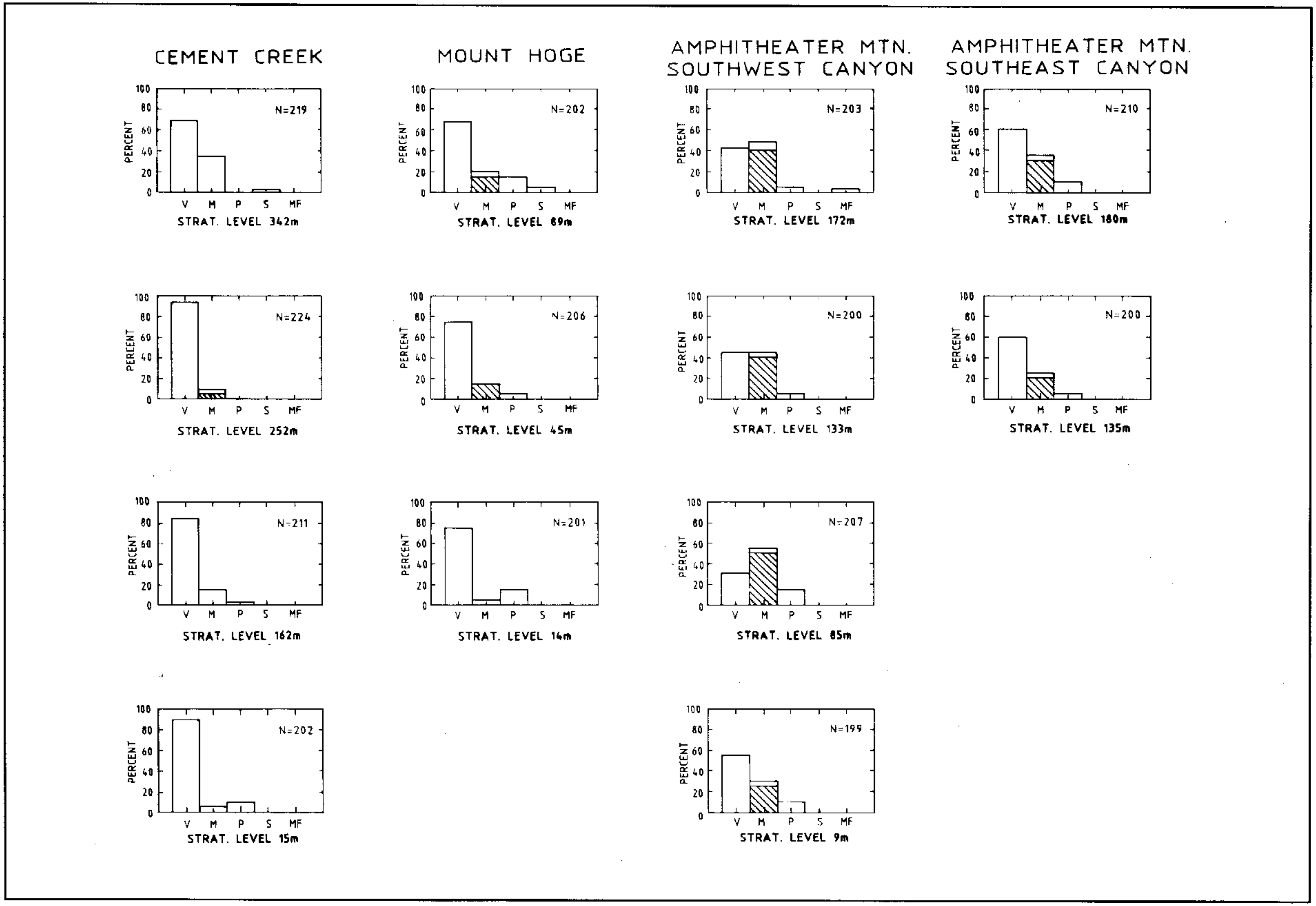

Figure 19: Clast-count data from the Amphitheatre Formation at four sections in the Burwash basin. n = number of clasts counted; STRAT.LEVEL = location of clast count on measured section; V = volcanic clast; M = metamorphic clast (cross-hatched = meta-sedimentary)(blank = high-grade metamorphic); P = plutonic clast; S = sedimentary clast; MF = fine-grained mafic clast. See text for discussion.

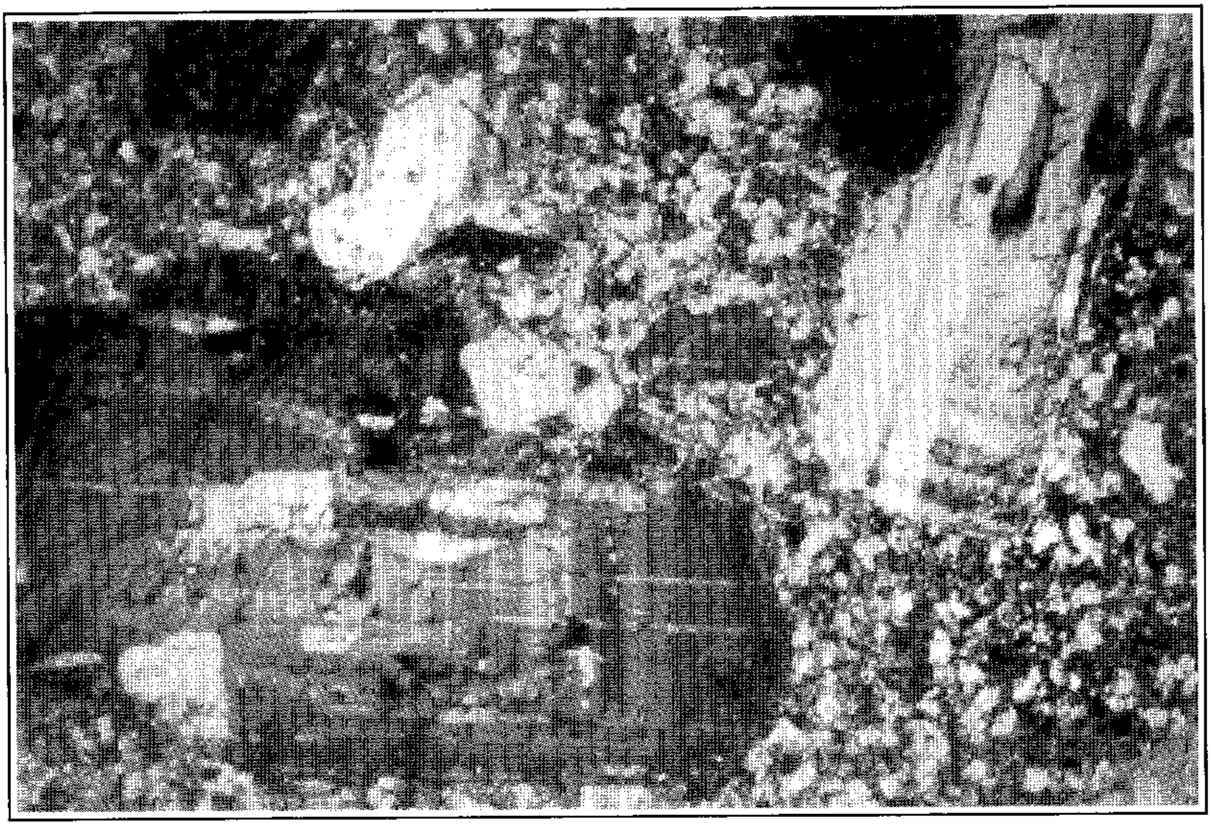

Figure 20: Photomicrograph of a typical meta-basalt conglomerate clast of the Amphitheatre Formation from the Burwash basin. Field of view is 2 mm.

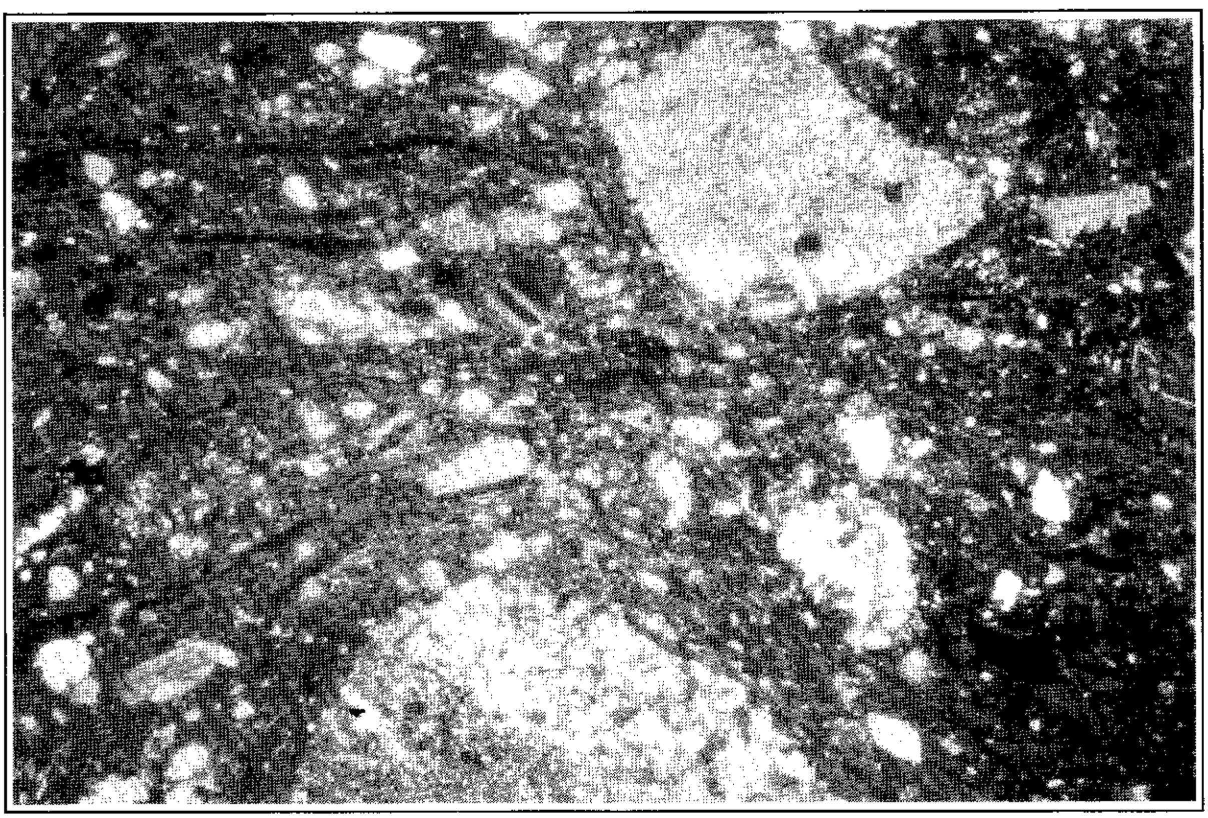

Figure 21: Photomicrograph of a typical welded-tuff conglomerate clast of the Amphitheatre Formation from the Burwash basin. Field of view is 2 mm.

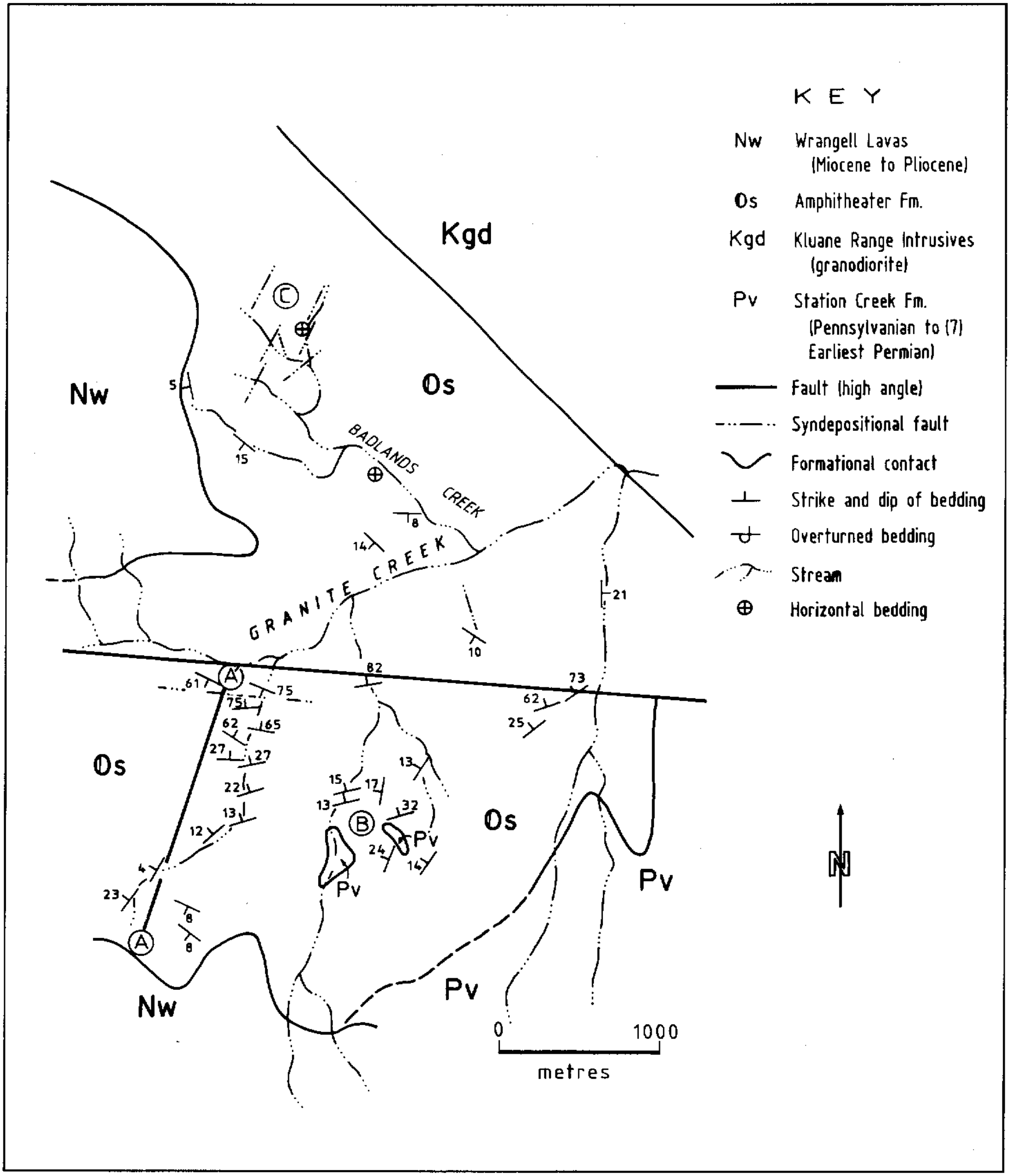

Figure 22: Geologic sketch map of the Amphitheatre Formation along the southern margin of the Burwash basin. See text for explanation.

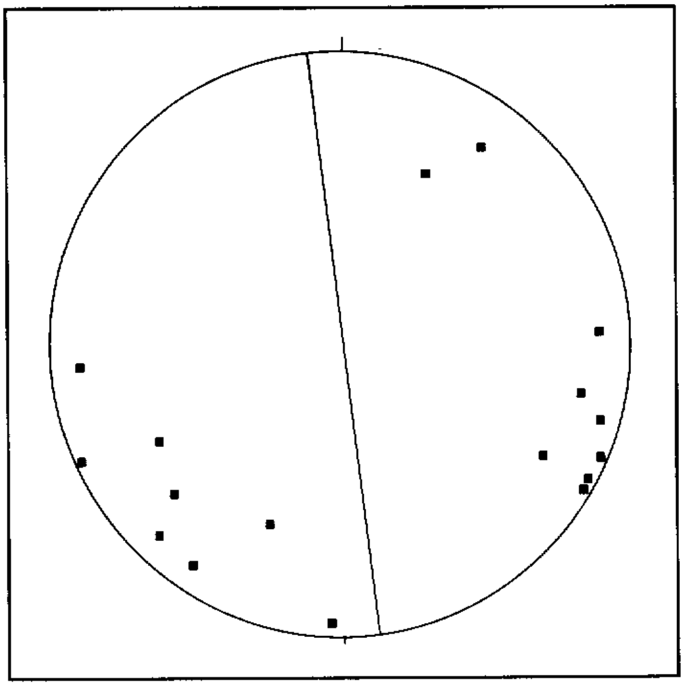

Figure 23: Equal-area projection of poles to 2° faults in the Burwash basin. The steeply dipping faults trend NW-SE. The dark line is the acute bisector of the two conjugate fault populations.

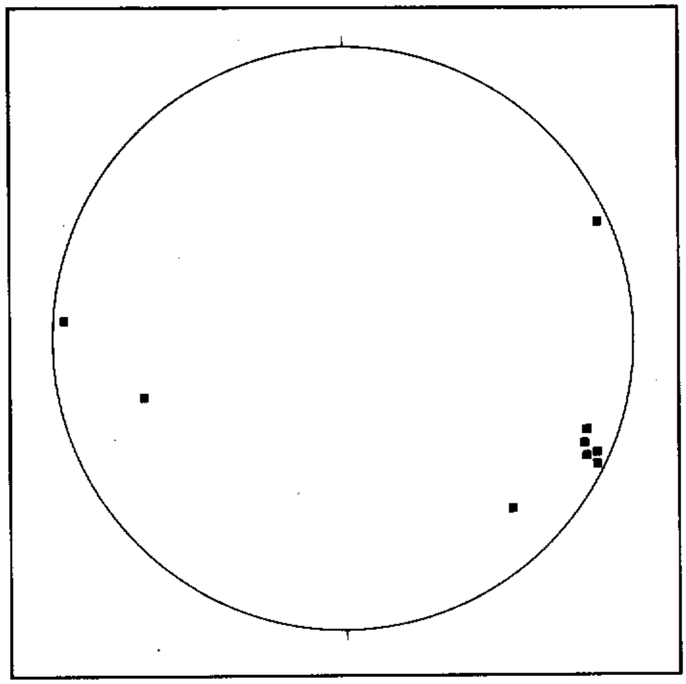

Figure 24: Equal-area projection of poles to 3° syndepositional faults in the Burwash basin. The steeply dipping faults trend northeast-southwest.

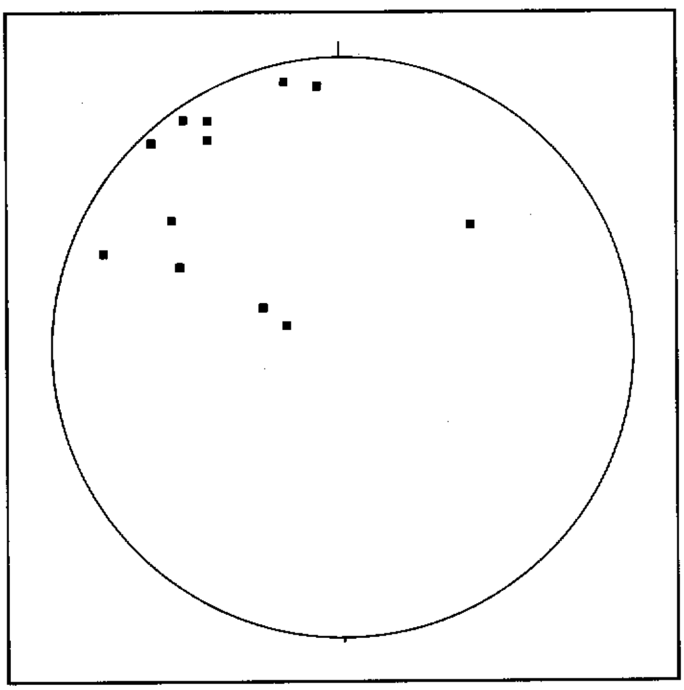

Figure 25: Equal-area projection of slickenside orientations from 2° faults in the Burwash basin. This array demonstrates a large component of horizontal displacement as well as a smaller component of vertical displacement.

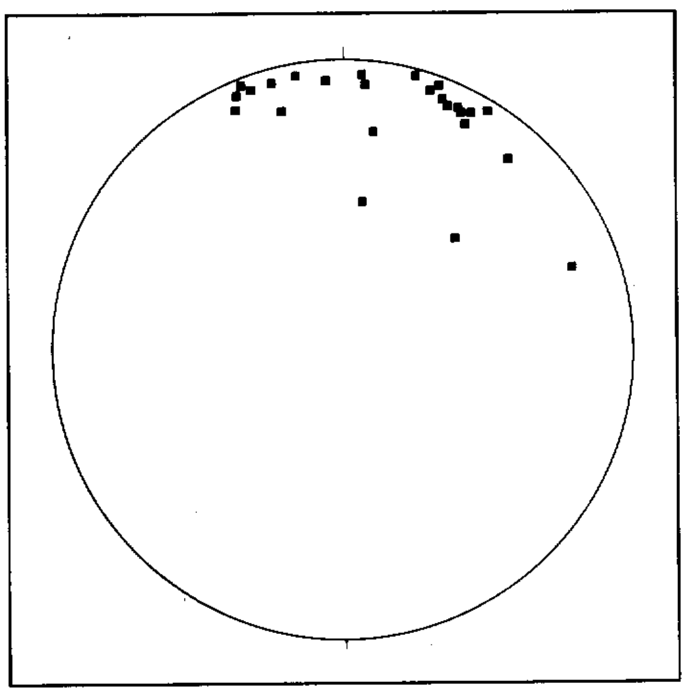

Figure 26: Equal-area projection of slickenside orientations on 3° syndepositional faults in the Burwash basin. This array indicates a large component of sub-horizontal displacement.

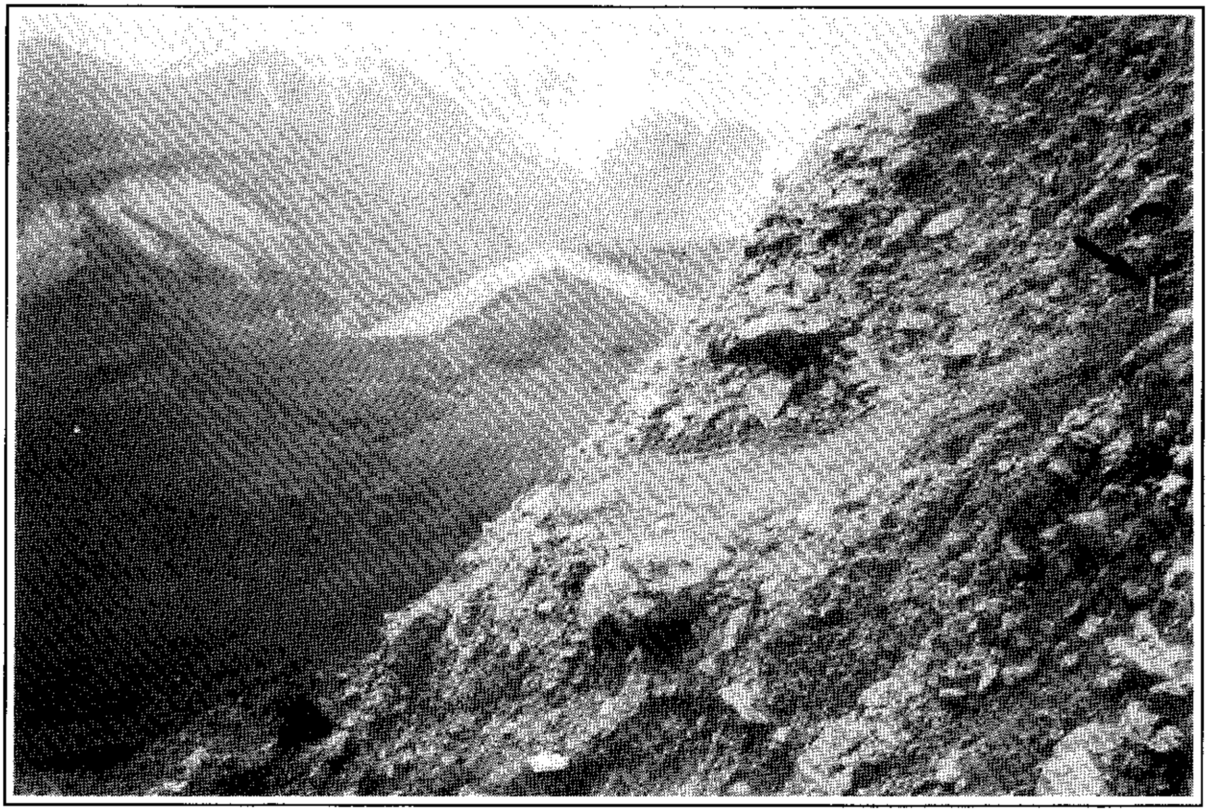

Figure 27: 30-m-thick monomictic boulder conglomerate composed of granodiorite clasts, some of which are up to 5 meters in diameter, exposed in the Burwash basin. Granodiorite clasts are uncommon in conglomerates lower in the section, indicating that a granodioritic source terrane was rapidly exposed along the Burwash basin. Hammer (arrow) for scale.

TABLE 1

Gch	Gravel, clast-supported, horizontal stratification		Granodiorite / basalt breccia
Gcmi	Gravel, clast-supported, massive, imbrication		Coal
Gcp	Gravel, clast-supported, planar cross-stratification	A	Volcanic-ash rich layer
St	Sand, trough cross-stratification		Conglomerate lenses
Sr	Sand, ripple stratification		\Sandstone lenses
Sm	Sand, massive		Plant fragments
Sh	Sand, horizontal stratification		Covered
Fsm	Silt, mud - massive		Volcanic sill
	Granodiorite breccia		Logs
			Burrows
			Siltstone Drape

Table 1: Lithofacies code for measured sections in the Amphitheatre Formation, Yukon Territory.

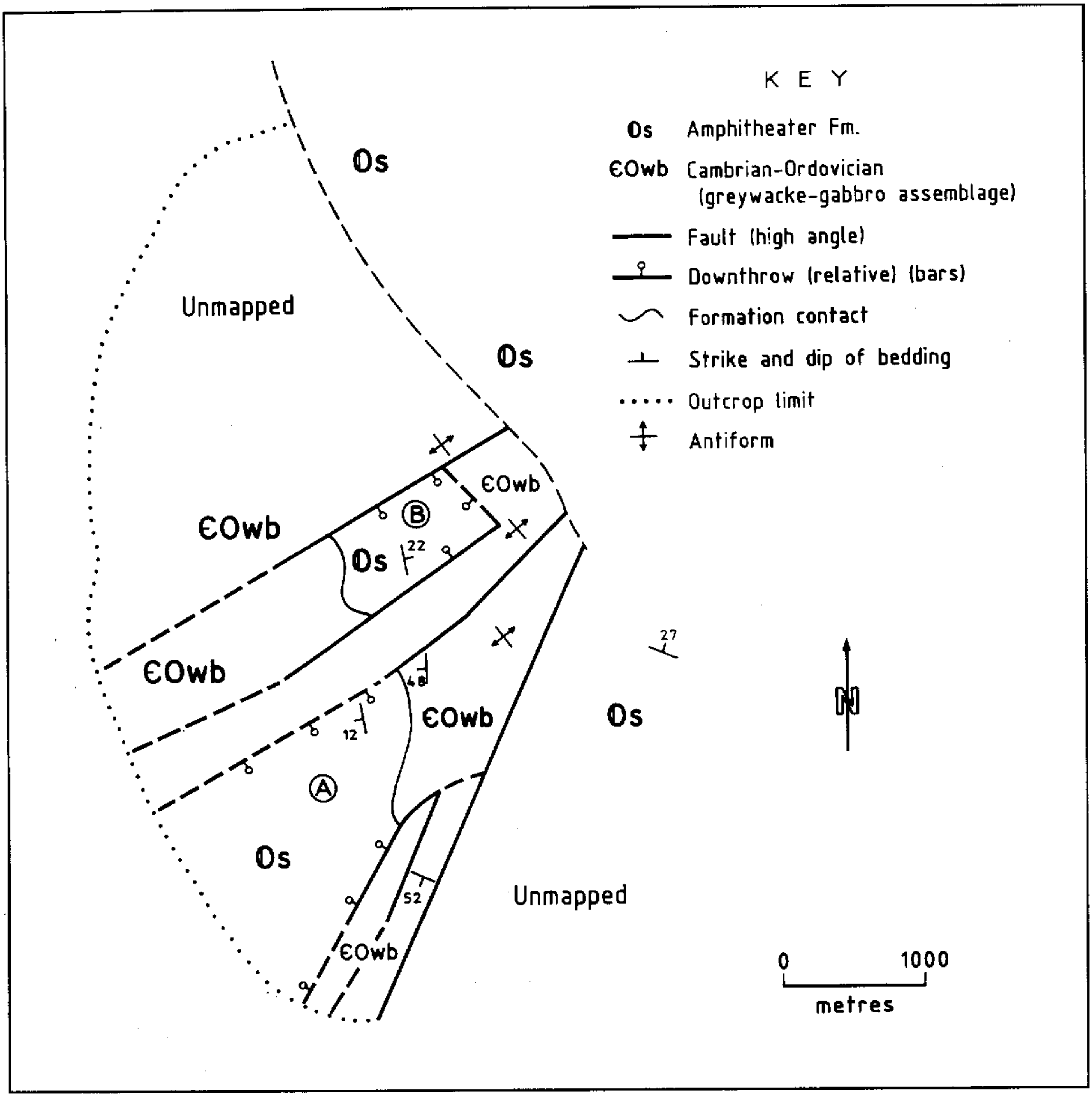

Figure 28: Geologic sketch map of the southwest margin of the Bates Lake basin demonstrating the extensional nature of this part of the basin. See text for explanation.

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